ESTCP
Cost and Performance Report

(MM-0535)

Final Demonstration of Helicopter Multi-Towed Array Detection Systems (MTADS) Magnetometry Technology for the ESTCP Wide Area Assessment Pilot Program

May 2008

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **01 MAY 2008**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Final Demonstration of Helicopter Multi-Towed Array Detection Systems (MTADS) Magnetometry Technology for the ESTCP Wide Area Assessment Pilot Program**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**59**	

COST & PERFORMANCE REPORT
Project: ER-0535

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

ACRONYMS AND ABBREVIATIONS

AGL	Above Ground Level
BT3	Bombing Target #3
BT4	Bombing Target #4
CERCLA	Comprehensive Environmental, Response, Compensation, and Liability Act
cm	centimeter(s)
CRADA	Cooperative Research and Development Agreement
Cs	cesium
CSM	Conceptual Site Model
DAQ	data acquisition computer
DAS	data acquisition system
DGM	digital geophysical mapping
DoD	Department of Defense
DSB	Defense Science Board
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Sites
GIS	Geographic Information Systems
GPS	Global Positioning System
HE	High Explosive
HeliMag	Helicopter MTADS Magnetometry
Hz	Hertz
IMU	Inertial Measurement Unit
kHz	kilohertz
LiDAR	Light Detection and Ranging
μS	microsecond(s)
m	meter(s)
mm	millimeter(s)
m/s	m/second
MEC	Munitions and Explosives of Concern
MMRP	Military Munitions Response Program
MTADS	Multi-sensor Towed Array Detection System
NDIA	New Demolition Impact Area

NRL	Naval Research Laboratory
nT	nanoTesla
OB/OD	open burn/open detonation
PBR	Precision Bombing Range
RTK GPS	Real Time Kinematic GPS
SORT	Simulated Oil Refinery Target
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator
WAA	Wide Area Assessment

ACKNOWLEDGEMENTS

Demonstration of Helicopter Multi-sensor Towed Array Detection System for ESTCP WAA Pilot Program, Cost and Performance Report provides an analysis of the cost of the low-airborne demonstrations conducted as part of the ESTCP WAA pilot program. This report summarizes the performance seen in demonstrations at multiple sites in terms of the acquisition, processing, analysis, and interpretation of magnetometry data. The work was performed by Sky Research, Inc. of Oregon, with Dr. John Foley serving as Principal Investigator and Mr. David Wright serving as co-Principal Investigator.

We wish to express our sincere appreciation to Dr. Jeffrey Marqusee, Dr. Anne Andrews, and Ms. Katherine Kaye of the ESTCP Program Office for providing support and funding for this project.

This page left blank intentionally.

1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

Munitions and explosives of concern (MEC) contamination is a high priority problem for the Department of Defense (DoD). Recent DoD estimates of UXO contamination across approximately 1,400 DoD sites indicate that 10 million acres are suspected of containing MEC. Because many sites are large in size (greater than 10,000 acres), the investigation and remediation of these sites could cost billions of dollars. However, on many of these sites only a small percentage of the site may in fact contain MEC contamination. Therefore, determining applicable technologies to define the contaminated areas requiring further investigation and munitions response actions could provide significant cost savings. Therefore, the Defense Science Board (DSB) has recommended further investigation and use of Wide Area Assessment (WAA) technologies to address the potential these technologies offer in terms of determining the actual extent of MEC contamination on DoD sites (DSB, 2003).

In response to the DSB Task Force report and recent Congressional interest, the Environmental Security Technology Certification Program (ESTCP) designed a Wide Area Assessment pilot program that consists of demonstrations at multiple sites to validate the application of a number of recently developed and validated technologies as a comprehensive approach to WAA. These demonstrations of WAA technologies include deployment of high airborne sensors, helicopter-borne magnetometry arrays and ground surveys.

This report documents the cost and performance of the demonstrations of Helicopter Multi-sensor Towed Array Detection System (MTADS) Magnetometry (HeliMag) technology at WAA pilot program demonstration sites as part of ESTCP project MM-0535. These demonstrations included the following:

- Former Pueblo Precision Bombing Range (PBR) #2, La Junta, Colorado
- Former Kirtland PBRs N2, N3, and New Demolitions Impact Area, Albuquerque, New Mexico
- Victorville PBRs Y and 15, Landers, California
- Former Camp Beale, Marysville, California
- Former Erie Army Depot Lake Erie Impact Area and Toussaint River, Ohio

HeliMag provides efficient low-altitude digital geophysical mapping (DGM) capabilities for metal detection and feature discrimination at a resolution approaching that of typical ground survey methods, limited primarily by terrain, vegetation, and structural inhibitions to safe low-altitude flight. The magnetometer data can be analyzed to extract either distributions of magnetic anomalies (which can be further used to locate and bound targets, aim points, and open burn/open detonation (OB/OD) sites), or individual anomaly parameters such as location, depth, and size estimate. The individual parameters can be used in conjunction with target remediation to validate the results of the magnetometer survey.

1.2 OBJECTIVES OF THE DEMONSTRATION

The purpose of the demonstrations was to survey WAA demonstration sites in areas amenable to low-altitude helicopter flight. Specific objectives of the demonstrations included:

- Identify areas of concentrated munitions, including the known and suspected target areas;
- Bound the target areas;
- Estimate density and distribution of munitions types and sizes;
- Characterize site conditions to support future investigation, prioritization, remediation, and cost estimation tasks.

A determination of success for these demonstrations was based on system performance, as summarized in Section 4.

1.3 REGULATORY DRIVERS

United States Army Corps of Engineers (USACE) is the lead federal agency under the Formerly Used Defense Site (FUDS) program. USACE administers the FUDS Military Munitions Response Program (MMRP) program using DoD investigation/cleanup methods based on the U.S. Environmental Protection Agency (USEPA) Comprehensive Environmental, Response, Compensation, and Liability Act (CERCLA) process.

1.4 STAKEHOLDER/END USER

ESTCP managed the stakeholder issues as part of the pilot program. ESTCP used a process to ensure that the information generated by the high-airborne, helicopter, and ground surveys was useful to a broad stakeholder community (e.g., technical project managers and Federal, State, and local governments, as well as other stakeholders).

1.5 DEMONSTRATION RESULTS

The results of the individual demonstrations are reported in the demonstration reports. In this report, we provide a summary of the results to characterize the use of HeliMag technology for WAA. As demonstrated, HeliMag technology can be used to help define the areas of concentrated munitions contamination. It is less important for the system to be used to detect individual munitions. Restrictions on the use of the technology can include some site restrictions, including topography, vegetation and geologic interference. The system performed best in terms of detection and production on large open sites without geologic interference.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

The Naval Research Laboratory (NRL) developed the MTADS technology. Use of this technology was transferred to Sky Research for commercialization via a Cooperative Research and Development Agreement (CRADA). Prior to the transfer, this technology was fully evaluated for the DoD by ESTCP (Nelson et al. 2005; Tuley and Dieguez 2005).

2.2 TECHNOLOGY DESCRIPTION

The HeliMag system includes a helicopter-borne array of magnetometers and software designed specifically to process data collected with this system and perform physics-based analyses on identified targets (Table 1). These technologies are described in greater detail in the following subsections.

Table 1. Sky Research HeliMag Technology Components

Technology Component	Specifications
Geophysical Sensors	7 Geometrics 822 cesium (Cs) vapor magnetometers, 0.001 nanotesla (nT) resolution
Global Positioning System (GPS) Equipment	2 Trimble MS750 GPS receivers, 2-3 centimeter (cm) horizontal precision
Altimeters	1 Optech laser altimeter and 4 acoustic altimeters, 1 cm resolution
Inertial Measurement Unit (IMU)	Crossbow AH400, 0.1 degree resolution
Data Acquisition System[1] (DAS)	NRL Data Acquisition Computer (DAQ) SKY DAS
Aircraft[2]	Bell Long Ranger helicopter Hughes MD530F helicopter Hughes MD500D helicopter

[1] The NRL DAQ was used for the demonstrations at Pueblo, Kirtland and Victorville PBRs. The SKY DAS was used for the demonstrations at the Toussaint River site and at Former Camp Beale.
[2] The Bell Long Ranger helicopter was used for the demonstrations at Pueblo, Kirtland and Victorville PBRs. The Hughes MD530F helicopter was used for the demonstration at the Toussaint River site. The Hughes MD500D helicopter was used for the demonstration at Former Camp Beale.

2.2.1 Helicopter Platform

Sky Research used three helicopter platforms for the demonstrations: a Bell Helicopter Model 206 helicopter (Figure 1) for data collection at the Pueblo PBR #2, Kirtland PBRs, and Victorville PBR; a Hughes MD530F helicopter was for the demonstration at the Former Erie Army Depot Lake Erie Impact Area and Toussaint River (Figure 2); and a Hughes MD500D for the demonstration at Former Camp Beale. The helicopter platforms were used to deploy the geophysical sensors, GPS equipment, altimeters, IMU, and DAS technologies listed in Table 1. Because the magnetic signal falls off quickly with distance, helicopters are typically flown at survey altitudes of 1-3 meters (m) above ground level (AGL).

Onboard navigation guidance displays provided pilot guidance, with survey parameters established in a navigation computer that shared the real-time kinematic GPS (RTK GPS) positioning data stream with the DAS. Survey courses were plotted for the pilot in real time on the display. The sensor operator monitored presentations showing the data quality for the altimeter and GPS and the GPS navigation fix quality; this allowed the operator to respond to both visual cues on the ground and to the survey guidance display. Following each survey, the operator had the ability to determine the need for surveys of any missed areas before leaving the site.

Figure 1. Helicopter MTADS Technology as Deployed on Bell Long Ranger Helicopter for Demonstrations at Pueblo, Kirtland and Victorville PBRs.

Figure 2. Hughes MD530F Helicopter Used for the Demonstration at the Toussaint River Site in Ohio.

2.2.2 Sensors and Boom

The MTADS magnetic sensors were Geometrics 822A Cs vapor full-field magnetometers (a variant of the Geometrics 822). The array of seven sensors was interfaced to the DAS and the sensors were evenly spaced at 1.5 m intervals on a 9 m Kevlar boom mounted on the helicopter.

2.2.3 Positioning Technologies

Two Trimble MS750 RTK GPS receivers were used to provide positions and platform attitude at 20 hertz (Hz), with four acoustic altimeters for recording the altitude of the platform. An IMU

was used to correct for platform pitch. The DAS was aligned with the GPS Universal Time Coordinated (UTC) time. The GPS time stamp was used as the basis for merging position data with sensor information.

RTK GPS was also used to generate positions for ground surveying. Sky Research utilized an in-house professional land surveyor to ensure that geospatial data maintained accurate ties to the local coordinate system.

2.2.4 Data Acquisition Systems

Two different systems were used for these demonstrations: the NRL DAQ (Pueblo, Kirtland and Victorville demonstrations) and the SKY DAS (Toussaint River and Former Camp Beale demonstrations). The new DAS was developed by Sky Research for use with the helicopter system in early 2006, providing a number of advantages over the previous DAQ used for the earlier demonstrations, including smaller footprint, Linux operating system, more accurate time stamping, and faster sampling rate. The DAS logged magnetometer data at 400 Hz; the data were down-sampled to 100 Hz providing the same nominal down-the-track sample interval as in the previous demonstrations.

2.2.5 Data Processing

Data were downloaded via computer disks and uploaded via the Internet after each survey mission. A data processing overview is outlined in the flow diagram provided in Figure 3.

For the Pueblo, Kirtland and Victorville demonstrations, data processing was performed using custom application software running under the Oasis Montaj (Geosoft Ltd., Toronto, Canada) geophysical data processing environment. For the Toussaint River and Former Camp Beale demonstrations, UXOLab software was used for data processing; this software contains all the functionality required to process raw geophysical data, detect anomalous regions and perform geophysical inversions.

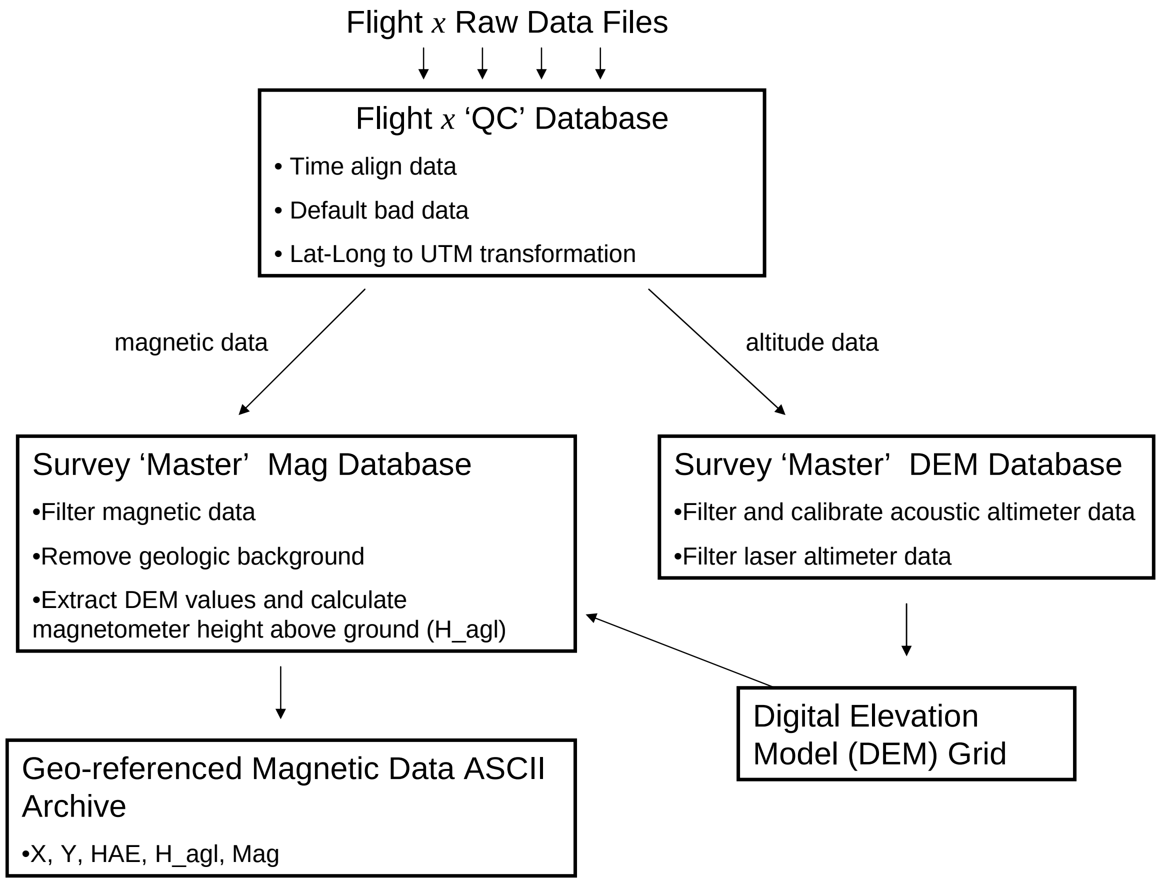


Figure 3. Helicopter MTADS Processing Flow Chart.

2.2.6 Data Analysis

Anomalies were selected using an automated target selection methodology. Automatic target selection for WAA surveys has the advantages of being objective, repeatable, and much faster than manual selection. However, automatic target pickers are not yet sophisticated enough to reliably detect closely spaced targets and targets that are at or below the same amplitude as the local geologic signal and do not perform well in areas of high target density. To avoid selecting an excessive number of false targets, automatic target selection routines were only used to select targets with response amplitudes significantly above the background geologic noise.

The limitations of automatic target selection are not as detrimental for WAA purposes as they would be for individual target selection. The challenge is to calibrate the automatic target selection routine so that the number of valid targets of interest selected is maximized, while minimizing the number of anomalies attributable to geologic noise selected. To achieve this, manual target selection results were compared with those obtained using an automated target selection routine over a representative subset of each demonstration site. The results of the comparisons were used to fine-tune the parameters for automatic target selection.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

Previous testing of the helicopter magnetometry technology in general was supported by ESTCP (Nelson et al. 2005). The primary development objective was to provide an MEC site characterization capability for extended areas, while retaining substantial detection sensitivity for individual MEC. The system included data collection hardware in the form of a helicopter-borne array of magnetometers, and software designed to process data collected with this system and to perform physics-based analyses on identified targets.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

As with all characterization technologies, site-specific advantages and disadvantages exist that strongly influence the level of success of their application.
Advantages of HeliMag technologies include:

- the ability to characterize very large areas;
- the ability to characterize difficult access areas and
- in areas requiring coverage of significantly large acreage, lower cost per acre surveyed than ground-based DGM methods.

Limitations of HeliMag technologies include:

- as a WAA tool, not intended to detect individual MEC;
- constraints on use due to site physiography, such as terrain, soils, vegetation and geology; and
- limited to shallow water areas due to height above target limitations of the technology.

This page left blank intentionally.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

Performance objectives are a critical component of the demonstration because they provide the basis for evaluating the performance and costs of the technology. For this demonstration, both primary and secondary performance objectives were established. Table 2 lists performance objectives, criteria and metrics used for evaluation.

3.2 TEST SITE SELECTION

In 2005, ESTCP created the WAA pilot program in response to the DSB Task Force report and Congressional interest, to validate the application of a number of recently developed technologies as a comprehensive approach to WAA. The WAA pilot program demonstration sites were selected based on criteria selected by the ESTCP Program Office in coordination with the WAA Advisory Group.

3.3 TEST SITE HISTORY/CHARACTERISTICS

The ESTCP site selection process resulted in the selection of three sites in 2005 for the first phase of the WAA demonstration: Pueblo PBR, Kirtland PBR and Borrego Military Wash. When site restrictions prevented the completion of the WAA demonstration at Borrego, Victorville PBR was added to the program. In 2006, additional sites were incorporated into the pilot program to evaluate performance under more challenging site conditions to further evaluate WAA technologies. The helicopter technology was subsequently demonstrated at the Toussaint River site and Former Camp Beale in this second phase of WAA demonstrations. Maps showing demonstration locations and boundaries are provided in Appendix B.

3.3.1 Pueblo PBR #2, CO

Pueblo PBR #2 was used as a World War II-era military training facility, located in the southern part of Otero County, Colorado. A 7,500-acre demonstration area was selected that encompassed two documented bombing targets (Bombing Targets #3 and #4 [BT3 and BT4]) and a suspected 75-millimeter (mm) air-to-ground gunnery target area.

Overall, the demonstration area was amenable to low altitude helicopter flight and was comprised primarily of rolling terraced terrain and vegetated with prairie grass and small shrubs. Land within the study area is primarily in Federal ownership managed by the U.S. Forest Service as the Comanche National Grasslands with portions leased to private owners for cattle grazing or owned by the State of Colorado.

Table 2. Performance Objectives for Helicopter Magnetometry Demonstrations

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Performance Confirmation Method	Performance Achieved				
				Pueblo PBR #2	Kirtland PBRs	Victorville PBRs	Former Camp Beale	Lake Erie Impact Area and Toussaint River
Qualitative (Primary)	Ease of use and efficiency of operations	Efficiency and ease of use meets design specifications	General observations	Pass	Pass	Pass	Pass	Pass
Quantitative (Primary)	Geo-reference position accuracy for each sensor system	Horizontal: < 0.25 m Vertical: < 0.5 m	Comparison of calibration target dipole fit analysis position estimates (in 3 dimensions) to ground truth.	Within 0.25 m	Horizontal: 0.06 m; Vertical: 0.15 m	Horizontal: 0.19 m; Vertical: 0.29 m	Horizontal: 0.24 m; Vertical: 0.22 m	Horizontal 0.13 m; Vertical 0.16 m
Quantitative (Secondary)	Survey coverage	>0.95 of planned survey area	Actual # acres surveyed/Planned # of survey acres	>0.95 of planned survey area	99.8% actual areas surveyed (gaps due to obstacle/terrain are excluded from calculations)	98.6%	98.7%	99.9%
	Operating parameters (altitude, speed, overlap, production level)	1-3 m AGL; 15-20 m/s; 10%; 300 acres/day	Field data logs used to calculate the operating parameters.	1-3 m AGL; 15-20 m/s (30-40 knots); 10%; 300 acres/day	Altitude: Mean 1.6 m (SD .35 m) Speed: Mean 17.8 m/s (SD 2.5 m/s) Overlap: 10% Production: 454 acres/day	Altitude: 2.1 m AGL Speed: mean 15.1 m/s, Production: 307 acres/day	Altitude: 2.1 m AGL Speed: mean 13.2 m/s, Production: 247 acres/day	Altitude: Mean 2.5 m AGL, SD 0.55 m; Speed: 8-13 m/s (15-25 kts); Overlap: 37%; Production Level: 400 acres/day

Table 3. Performance Objectives for Helicopter Magnetometry Demonstrations (continued)

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Performance Confirmation Method	Performance Achieved				
				Pueblo PBR #2	Kirtland PBRs	Victorville PBRs	Former Camp Beale	Lake Erie Impact Area and Toussaint River
Quantitative (Secondary) (continued)	Noise level (combined sensor/platform sources, post-filtering)	< 1 nT	Accumulation of noise from sensors and sensor platforms, including GPS, rotor noise, radio frequencies, etc. calculated as the standard deviation of a 20 sec window of processed data collected out of ground effect.	<1 nT	0.1 to 0.17 nT	0.24 nT	0.22 nT	0.11 nT
Quantitative (Secondary)	Data density/point spacing	0.5 m along-track 1.5 m cross-track	(# of sensor readings/sec) / airspeed	0.5 m along-track 1.5 m cross track	Along-track: Mean 0.178 m (SD .0025 m) Cross-track: 1.5 m	Along-track: Mean 0.15 m max 0.30 m Cross-track: Max: 1.5 m	Along-track: Mean 0.13 m max 0.29 m Cross-track: Max: 1.5 m	0.08 – 0.13 m along track; 1.5 m cross track (max)
	MEC parameter estimates	Size < 0.02 m; Solid Angle < 10º	The size and dipole angle estimates of the calibration items are consistent	Size <0.02 m; Solid Angle < 10º	Size: SD .07 m Solid Angle 6.0 º	Size: 0.17 m Solid Angle 4.4 º	Size: 0.011 m Solid Angle 8.75	Size: 0.012 m; Solid Angle: 3.6º

3.3.2 Kirtland PBRs, NM

The former KPBR is a 15,246-acre FUDS used as a World War II-era military training facility located in Albuquerque, New Mexico. A 5,000-acre demonstration area was selected and located in two areas on either side of Double Eagle Airport. The study area was known to contain three precision bombing targets identified as N-2, N-3, and New Demolition Impact Area (NDIA), as well as a simulated oil refinery target (SORT). The specific location of the SORT was unknown, but was thought to be somewhere in the north-central to western edge of the study area. Small additional areas were surveyed at a later date to provide additional data on possible contamination within the FUDS.

The topography, geology and vegetation of the site were amenable to low altitude airborne surveys. The study area was situated on a relatively flat terrace at about 6,000 feet elevation (mean sea level) atop the Rio Puerco Escarpment. Gently rolling terrain within the demonstration area generally varied by less than 50 feet in elevation and was not incised by any significant drainage. The soils within the WAA study area are deep, well-drained homogeneous sandy loams formed on loess parent material with low magnetic mineral content. The vegetation was short-grass prairie and cultivated fields with very few trees and shrubs and did not pose a constraint to HeliMag operations. The site is owned by the City of Albuquerque. The current use of the site includes a municipal airport, a shooting range, and a waste treatment facility.

3.3.3 Victorville PBRs, CA

The former Victorville PBR is a 5,540-acre FUDS used as a WWII-era military training facility, located approximately 100 miles northeast of the city of Los Angeles in San Bernardino County, California. The WAA study area was known to contain Demolition Bombing Target “Y”, which was reportedly used for high explosive (HE) demobilization bombs and PBR Target 15, used for low-altitude practice bombing.

The site is centered on Means Lake, a dry lake bed located between small mountain masses in the eastern Mojave Desert. The topographic complexity of the site posed constraints to accessibility for helicopter operations. The area was sparsely vegetated with desert brush and grasses; however, in some areas the heights of shrubs posed constraints to helicopter operations, requiring flights higher than normally flown for HeliMag. Additionally, portions of the site were characterized by magnetically active geology, which complicated the selection of anomalies of interest from the background noise caused by geology.

The majority of the site is controlled and managed by the Bureau of Land Management, with a small percentage of the site in the southern buffer zone area in private ownership with multiple owners. The site is used for recreation, including off-road vehicle recreation, camping, and target practice by the public and similar recreational use by the private owners on the privately owned areas. Data collection methods were altered to accommodate recreational use in the dry lake bed during helicopter operations.

3.3.4 Former Erie Army Depot Lake Erie Impact Area and Toussaint River, OH

The former Erie Army Depot is located along the southern shore of Lake Erie. This site and associated impact areas were used by the U.S. Army for artillery testing and as an ordnance storage and issue center. Approximately 96,000 acres within Lake Erie and 1,428 acres of adjacent lands (wetlands, beach and dry land) are classified as formerly used target areas. 3,300 acres were designated for the helicopter survey at the site.

The designated study site was located along the south shore of the western basin of Lake Erie and encompassed 3,300 acres and included the mouth of the Toussaint River, beaches and near-shore areas. Surveys of the shoreline areas were limited in some areas due to trees extending close to the water line. Multiple land uses occur within and near the study site; presence of the Davis-Besse Nuclear Power Station required aircraft information for the survey areas in its vicinity. In addition, coordination was required with Camp Perry for surveying within the boundaries of the Camp Perry range fan.

3.3.5 Former Camp Beale, CA

The Former Camp Beale site encompasses approximately 64,000 acres located in northern California near Marysville and immediately east of Beale Air Force Base. An 18,000-acre demonstration area was selected within the FUDS boundary; reconnaissance surveys were flown with the HeliMag system, at half-kilometer line spacing, within that area to quantify the geologic noise on-site. The results of these reconnaissance surveys were used by program office staff and Sky Research to define an approximately 5,000-acre area for 100% coverage using the HeliMag system. This demonstration area was selected because it presented a more challenging environment for WAA assessment, including environmental constraints in some areas of the site (topography, vegetation, magnetic geology. climate) as well as mixed munitions usage and multiple overlapping known target areas. The site currently has multiple private land owners and state ownership. The site has sparse residential development and is also used for recreation. Areas of the site have been proposed for residential development.

3.4 PHYSICAL SET UP AND OPERATION

3.4.1 Mobilization/Demobilization

Mobilization and demobilization for these demonstrations required ferrying the helicopter from various home base locations and/or survey sites to the demonstration sites; transporting equipment to the base of operations from either Ashland, Oregon, or survey site; and mobilizing sensor operators and ground teams to the base of operations. At the end of each demonstration, the helicopter was ferried to either another survey site or a home base of operations. The helicopter boom was disassembled and the boom and equipment demobilized to Ashland, Oregon, or another survey site. Personnel demobilized to their base of operations or another survey site. Targets were investigated at a later date by a different contractor as part of the WAA validation surveys conducted on behalf of ESTCP.

3.4.2 Ground Control

RTK GPS provided centimeter-accuracy real time positioning and was used with the HeliMag system. It was also used to generate positions for ground fiducials and for positioning ground calibration data and field verifications. The Sky Research in-house professional land surveyor ensured that geospatial data generated by the project maintain accurate ties to the local coordinate system.

3.4.3 Sensor Calibration Targets

A calibration line was established at each site and seeded with emplaced items. The calibration items were placed on the ground and surveys conducted twice daily at the start and end of each of data collection survey at two altitudes. The resulting signatures were compared to calculated responses to confirm the system operation. No targets were buried and no attempt was made to measure a probability of detection.

3.4.4 Period of Operation

The WAA helicopter demonstration surveys began in September 2005 with subsequent demonstrations in 2006 and 2007. A total of 23,961 acres were surveyed; average productivity ranged from 239 acres/day at Former Camp Beale to 484 acres/day at Toussaint River. Table 3 summarizes the dates, acres and average productivity for each site.

Table 3. Helicopter Magnetometry WAA Demonstrations Period of Operation, Acres Surveyed and Average Production

Demonstration Site	Period of Operation	Acres Surveyed (acres)	Avg. Production Rate (acres/day)
Pueblo PBR #2	September 8 - 20, 2005	5,020	456
Kirtland PBRs	October 3 – 15, 2005	5,002	454
Kirtland PBRs, additional areas	February 25, 2007	353	353
Victorville PBRs	March 25 - April 24, 2006	6,130	307
Toussaint River	September 9 – 15, 2006	3,389	484
Former Camp Beale	June 29 – July 19, 2007	4,067	239

3.5 ANALYTICAL PROCEDURES

3.5.1 Data Processing

During the first data processing stage, raw data for a given survey flight were time-aligned and transcribed from the various raw data files into a ‘flight’ database. Routines were run to automatically reject or ‘default’ invalid data. The GPS geographic position coordinates were transformed to WGS84 Universal Transverse Mercator (UTM) coordinates. At this point, the data were visually inspected to ensure both integrity and quality. This pre-processing stage is instrumentation-specific and the steps required to transcribe these data into a time-aligned database were dictated by the structure of the data outputs from each device and the manner in

which they were logged. Data were then processed using the data processing software. Typical production processing for 300-500 acres takes approximately eight hours of data processing to produce a raw data plot image.

During each day of the demonstrations, the project data processor conducted an initial review of the geophysical data to ensure that the data were within a reasonable range, free from dropouts/spikes and timing errors, and otherwise apparently valid. The data processing software provided the mean, maximum, minimum, and standard deviation for each data file. The summary was reviewed and the data visually inspected. If any problems existed, the project geophysicist assessed the problem(s) and made adjustments to the field operations as needed to ensure quality data collection. Additional processing steps include filtering, geologic trend removal, and smoothing, if needed.

3.5.2 Data Analysis

The use of an automatic target picking methodology was investigated as part of this demonstration. To investigate the use of automatic target picking for each demonstration, a comparison of the results of an automated target picking procedure versus manual target picking results was conducted over a representative section of the demonstration sites; results of each analysis are reported in the individual demonstration reports. While the automatic routines performed sufficiently in many areas, these automated routines are not able to differentiate among the targets of interest, local geologic anomalies, and non-UXO-like cultural sources (e.g. pipelines). Therefore, the decision to pick manually, or use an auto-picker then add/reject targets manually was made based upon the number of targets to be picked and the extent of geologic/cultural clutter.

Anomaly density analyses were conducted to visualize the distribution of anomalies across the study areas. A density raster was computed using a 100 m radius neighborhood kernel that assigned anomaly densities in anomalies per hectare to each cell in the raster. Simply described, at grid nodes of every two meters the number of targets that appear within a 100 m search radius were counted. This search radius provides the density in targets per 31,416 m^2. These values were then ‘normalized’ by diving by 3.1416 to provide density estimates in targets/hectare. The resulting data were gridded to provide anomaly density images.

Target dipole fit analyses were conducted using the MTADS dipole fit algorithm (using the UX Analyze environment). This analysis derives the parameters for a model dipole that best fits the observed data. These parameters include horizontal position, depth, size, and solid angle (i.e., the angle between the Earth’s magnetic field vector and that of the dipole model). This analysis was conducted on each target from the calibration line passes and the derived parameters examined for accuracy (determined as the average error where relevant) and repeatability (indicated by the standard deviation. This analysis was also conducted on a subset of selected targets and used to down-select candidate targets for intrusive investigation (performed by another contractor). The results of the intrusive investigation were used for validation purposes.

This page left blank intentionally.

4.0 PERFORMANCE ASSESSMENT

4.1 RESULTS

4.1.1 Calibration

The data collected over each target from the calibration line passes were analyzed and parameters for a model dipole that best fits the observed data determined. These parameters, horizontal position, depth, size, and solid angle, were examined for accuracy and repeatability. Results were reported for each demonstration; Table 4 provides example results for the Kirtland PBRs demonstration.

Table 4. Calibration Results for Kirtland PBRs

Dipole Fit Parameter	Bias	Standard Deviation
Easting	0.02 m	0.09 m
Northing	0.06 m	0.13 m
Depth	0.15 m	0.13 m
Size	n/a	7 mm
Solid Angle	n/a	6.0 º

Data repeatability was assessed by comparing positioning and fitted parameters results. Figures 4-7 illustrate these results for the Kirtland PBRs demonstration. In general, results were found to be consistent in the demonstrations and within expected values. The fitted size and angle estimates were used to verify that estimates fell within the expected range for a given target as these estimates for any given munitions item varies considerably depending upon the alignment of the object with the Earth's magnetic field.

4.1.2 Anomaly Selection

For the purposes of WAA, the main goal is to delineate target density throughout the survey site. Anomaly density mapping for each of the WAA demonstration sites is included in Appendix C. As discussed, target selection can be accomplished either manually or through automated routines; the geologic background signal largely determines what methods are best for a given site. Table 5 provides a summary of anomaly selection and methodologies used for each demonstration site.

Table 5. WAA Demonstration Site Anomaly Selection Summary

Demonstration Site	Anomalies Selected	Selection Methodology
Pueblo PBR#2	12,735	Automated
Kirtland PBRs	23,648	Automated
Kirtland additional areas	5,300	Automated
Victorville PBRs	6,319	Manual
Toussaint River	1,904	Manual
Former Camp Beale	15,703	Manual

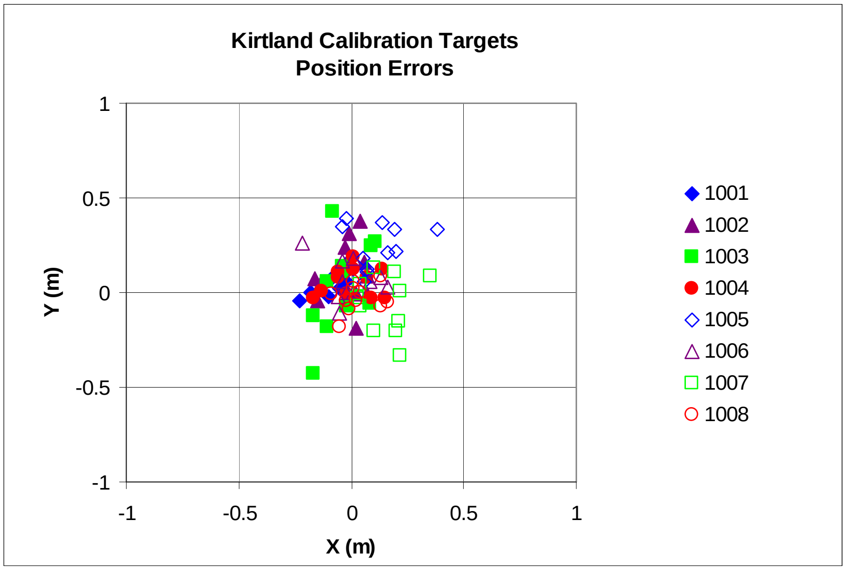


Figure 4. Derived Positions for Each Target Relative to the Ground Truth Supplied at Kirtland Site.

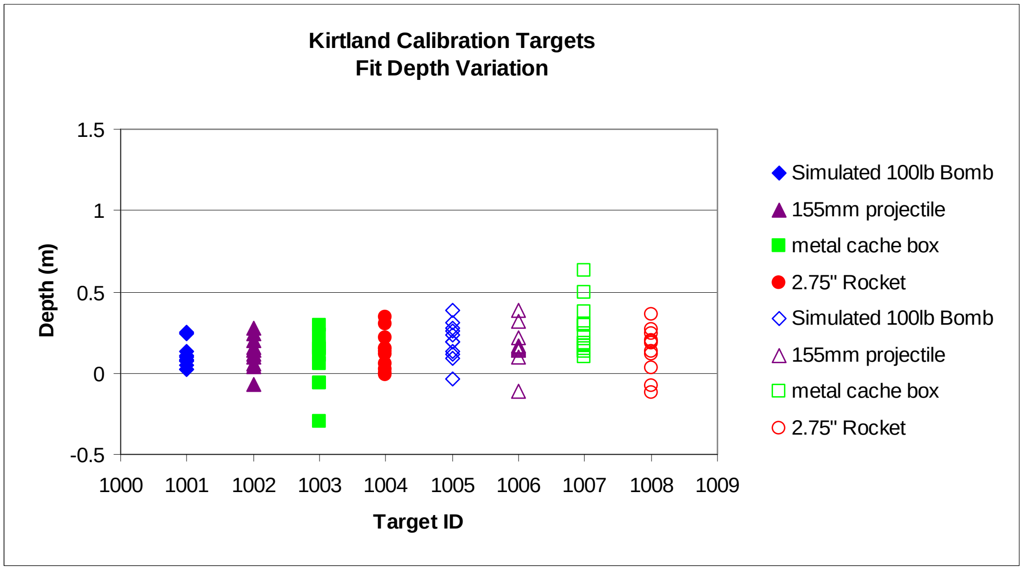


Figure 5. Dipole Fit Depth Estimates for Calibration Line Targets at Kirtland Site.

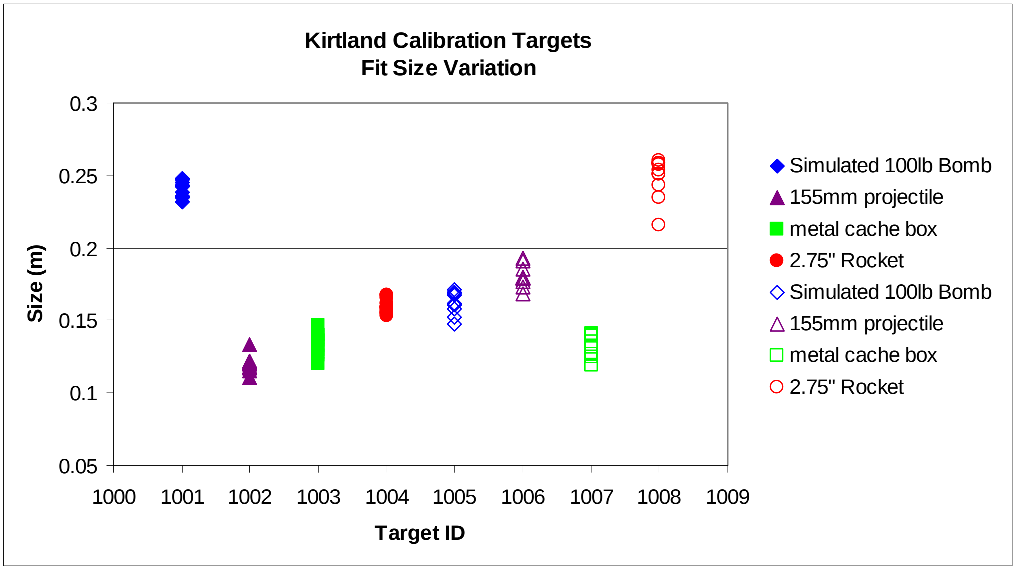


Figure 6. Dipole Fit Size Estimates for Calibration Line Targets at Kirtland Site.

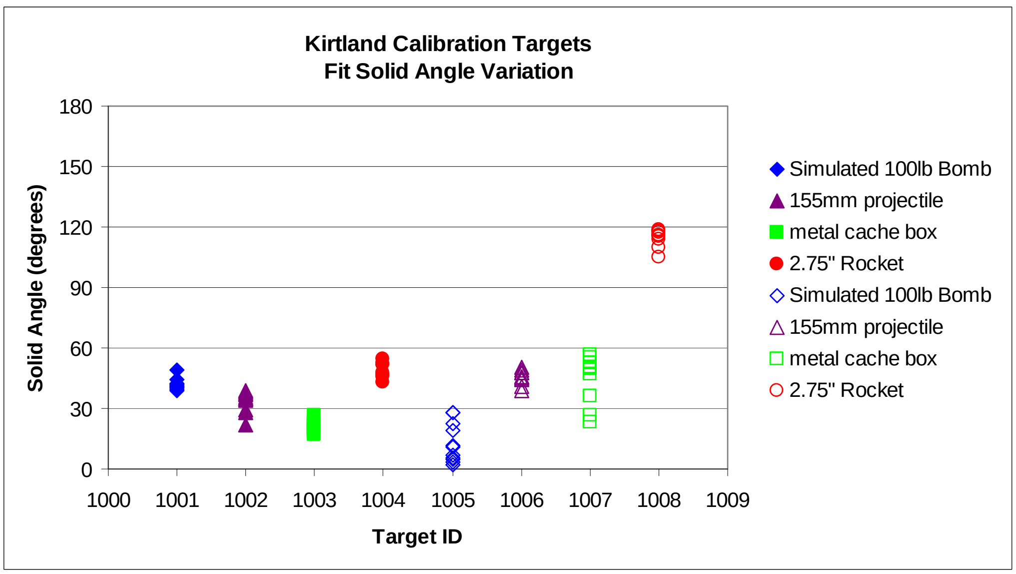


Figure 7. Dipole Fit Solid Angle Estimate for Calibration Line Targets at Kirtland Site.

4.1.3 Anomaly Density Analysis

Anomaly density analyses were conducted for each demonstration site to visualize the distribution of anomalies across the sites. The density analyses helped to define the extent of munitions contamination bounding target areas. An example anomaly density analysis is provided in Figure 8 for the Pueblo PBR #2 demonstration site.

4.1.4 Target Dipole-Fit Analyses

A subset of anomalies for each demonstration were analyzed using the dipole fit analysis methodology. In the demonstration performance assessments, the dipole fit results were compared to the expected character of MEC at each site as presented in the original Conceptual Site Models (CSM).

4.1.5 Intrusive Investigation Results

A number of targets were selected for intrusive investigation to supply ground truth for each demonstration. The dig program included anomalies detected by both the HeliMag system and the vehicular towed system (not a Sky Research endeavor). The dig results were compared to the anomalies detected. Results were documented in the final demonstration reports. An example is provided in tabular form in Table 6 for the Kirtland demonstration and in chart form in Figure 9.

Table 6. Dig Results Comparison for HeliMag and Vehicular Towed System at Kirtland

Dig Result	HeliMag	Vehicular	Combined
Intact MEC	5 (1%)	0 (0%)	5 (1%)
MEC related scrap	322 (81%)	244 (64%)	566 (73%)
Non-MEC related scrap	16 (4%)	48 (13%)	64 (8%)
No finds	56 (14%)	87 (23%)	143 (18%)
Totals	**399**	**379**	**778**

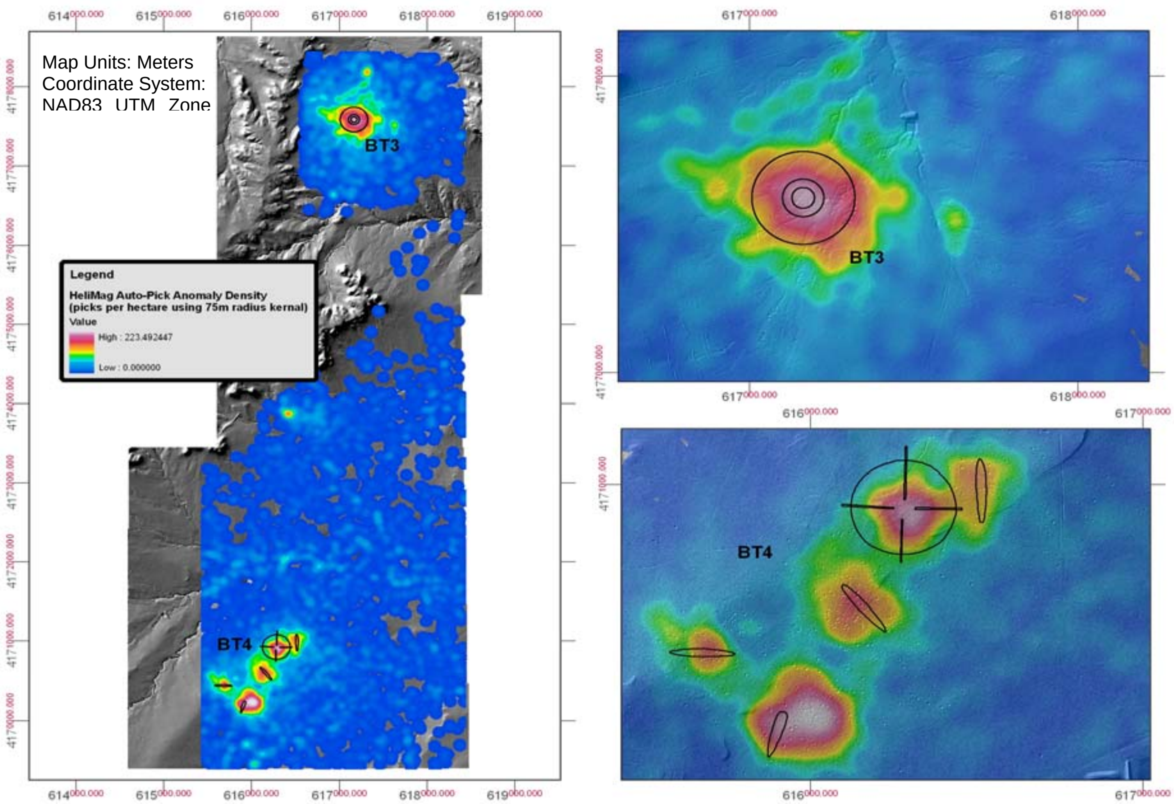


Figure 8. HeliMag Anomaly Pick Density Surface (anomalies per hectare) with Enlarged Density Images over the Two Suspected Bombing Targets at the Pueblo Site.

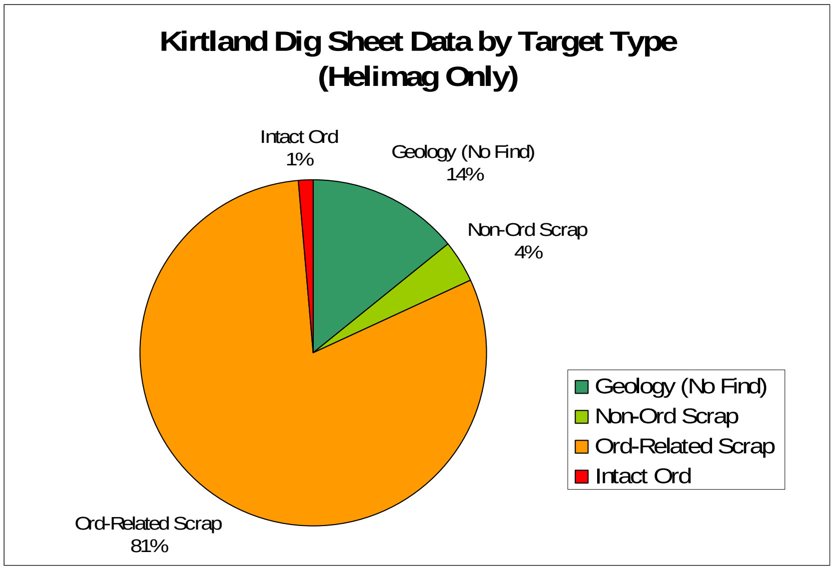


Figure 9. Intrusive Investigation Results for All Selected Anomalies. These Results are an Aggregate of the Results from Each Area Selected for Intrusive Investigation.

4.1.6 Target Area Detection

The results from the HeliMag analysis were used as part of the WAA process to confirm and bound targets at the demonstration site. The results from each demonstration site are summarized briefly below.

At Pueblo, the anomaly density analysis computed from HeliMag anomalies showed concentrated densities in relation to the BT3 and BT4 target areas (as shown in Figure 8). In each of these regions, the ship targets and aiming circles detected in the orthophotography and light detection and ranging (LiDAR) datasets coincided with significant elevations of magnetic anomaly density derived from the HeliMag data. The HeliMag results provide strong corroborating evidence supporting the existence of additional ‘ship’ targets near BT4 that were not part of the original CSM. A clearly defined high anomaly density area was not identified in the 75-mm target area; however, the combination of rough terrain and a substantial number of trees limited the ability to conduct surveys over the entire suspected target area at a low enough altitude to detect 75-mm munitions. . Subsequent ground surveys, which covered the area more completely than the helicopter surveys, did not find evidence for the 75-mm target area. Additional munitions response features identified in the high airborne datasets included an area north of BT3, a berm in the east central area of the demonstration site, and a barn or other ranching structure in the west central area of the demonstration site. HeliMag data were reviewed and these areas showed slight elevations in anomaly density (or no elevation at all in the case of the berm); however, none of these densities were consistent with high concentrations of MEC.

At Kirtland, the HeliMag technology confirmed the presence of the N-2, N-3 and SORT and NDIA areas. In the N-2 target circle area, the data clearly showed high concentrations of anomalies and the spatial extent of elevated ferrous material density was centered roughly on the target circle presented in the CSM. In the N-3 area, the results showed that the extent of the target was not a single elongated impact area as originally identified in the original CSM. The main impact area appeared to be circular with a number of smaller ‘satellite’ areas of elevated concentrations. Based upon these results, an additional survey was conducted along the western boundary in 2007 to determine the full extent of the elevated density regions in this area (Figure 10). It was postulated that some of the smaller ‘satellite’ high anomaly density areas may be due to the storage of MEC as described in the CSM. Within the CSM boundaries of the SORT area, the anomaly density analysis showed a roughly circular area of high anomaly concentration centered just south of the midline of the western boundary. Within the CSM boundaries of the NDIA area, 230 anomalies were detected. The NDIA area target density was found to be considerably lower than the other impact areas. Last, there are a number of areas of interest that were identified based solely upon the anomaly density analysis results. These areas were associated with a general increase in geologic response that was assumed to be the cause of the elevated anomaly densities; therefore, these areas were not evaluated further using advanced analyses or intrusive investigations.

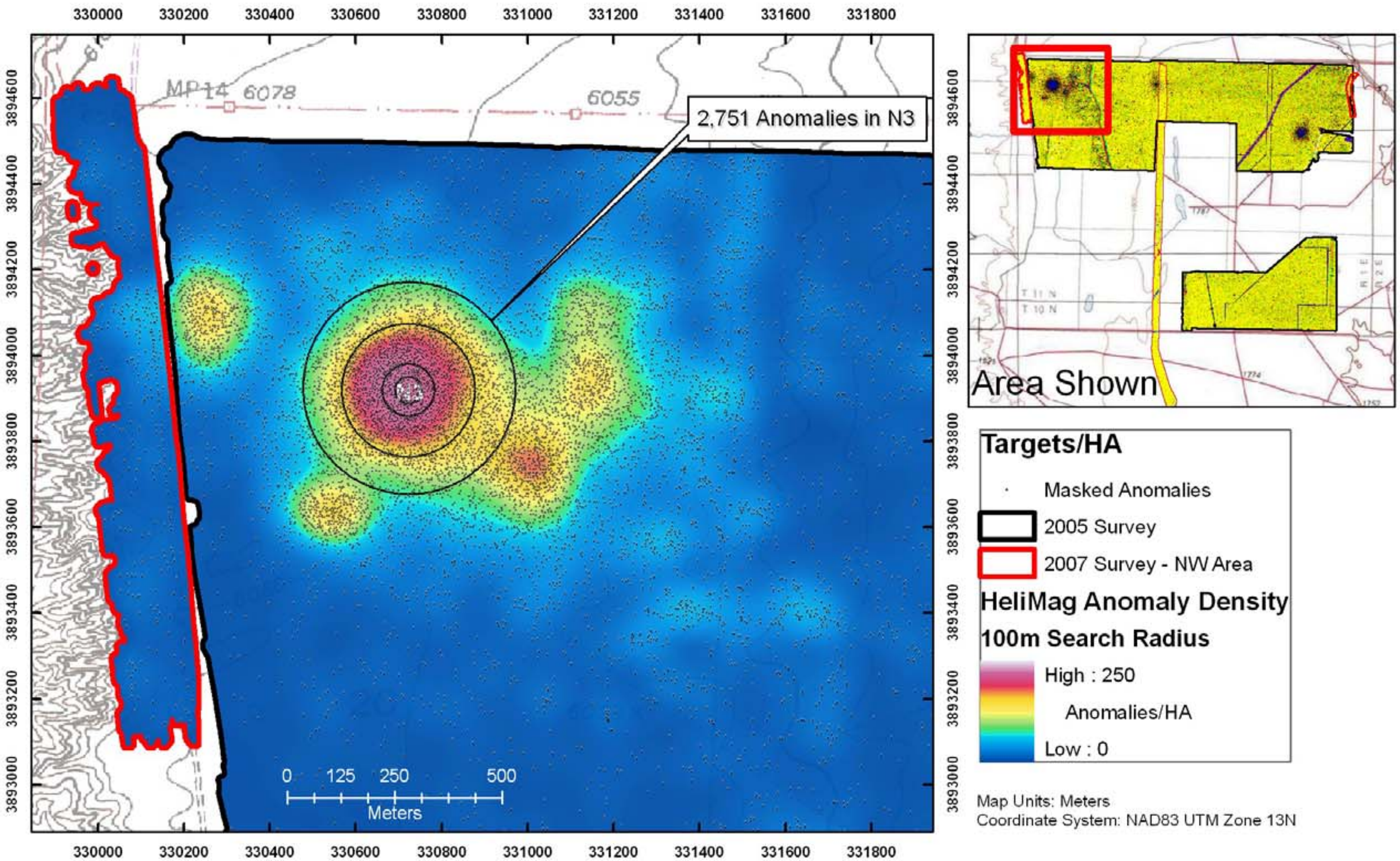


Figure 10. HeliMag Target Density and Anomalies at the Kirtland Demonstration Site in the N-3 Target Area Identified in the CSM.

At Victorville, HeliMag confirmed the location of the PBR 15 target area based on anomaly concentration. Within the Means Lake area, the number of anomalies expected to be associated with a target area were not detected (Figure 11). The use of HE bombs in this area may have resulted in fragments too small to be detected by magnetometers deployed at the helicopter stand-off distances required for safe flight.

At Former Camp Beale (Figure 12), the helicopter magnetometry data were successfully used to identify elevated concentrations of surface and subsurface anomalies in benign parts of the site, but much of the portion of the site suitable to low-level flight contained significant geological interference. This use of helicopter technology was severely limited at this site due to terrain, vegetation, and geology, but these areas were effectively avoided by incorporating site knowledge into the demonstration plan (Sky Research, 2007).

At the Toussaint River site, the distance of the sensor above potential targets was increased because of the water depth. As a result of the increasing water depth, the target density estimates were skewed to show lower target densities as the water gets deeper. Overall, the results showed several concentrations very near the shoreline (Figure 13). All of the targets that could be characterized were consistent in size with large projectiles known to be used at the site.

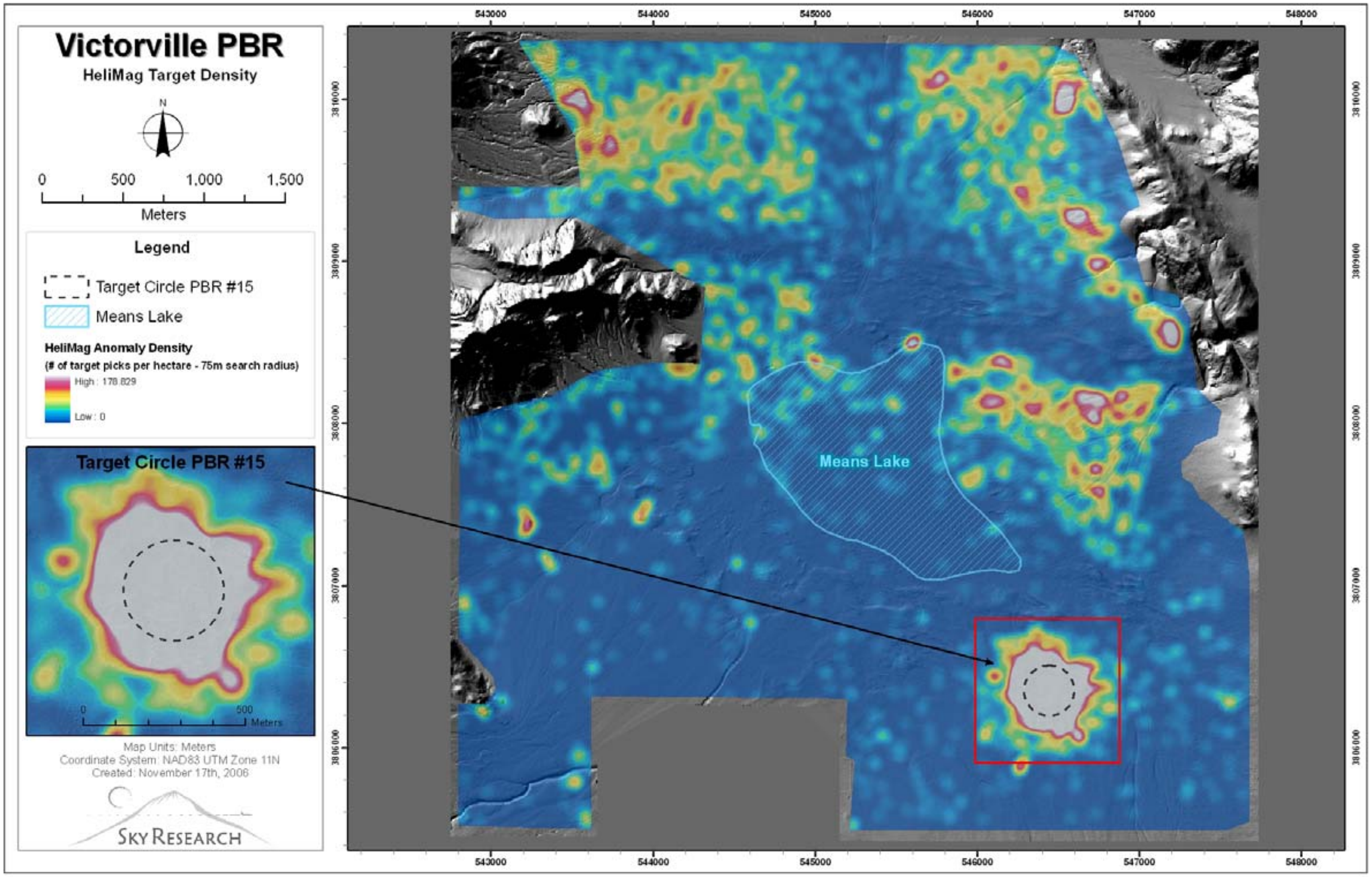


Figure 11. HeliMag Anomaly Density Analysis at Victorville PBRs.

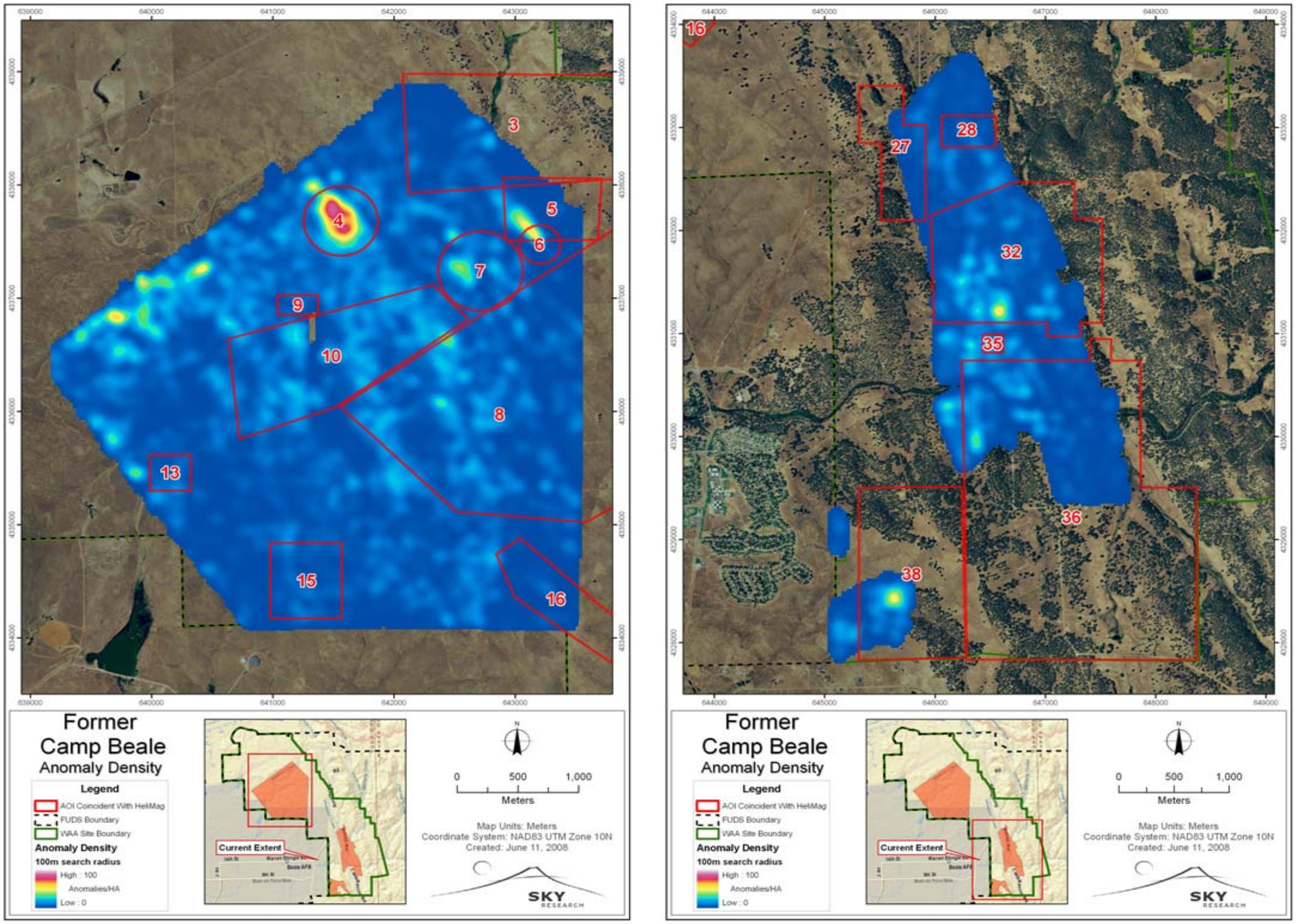


Figure 12. HeliMag Anomaly Density Analysis at Former Camp Beale.

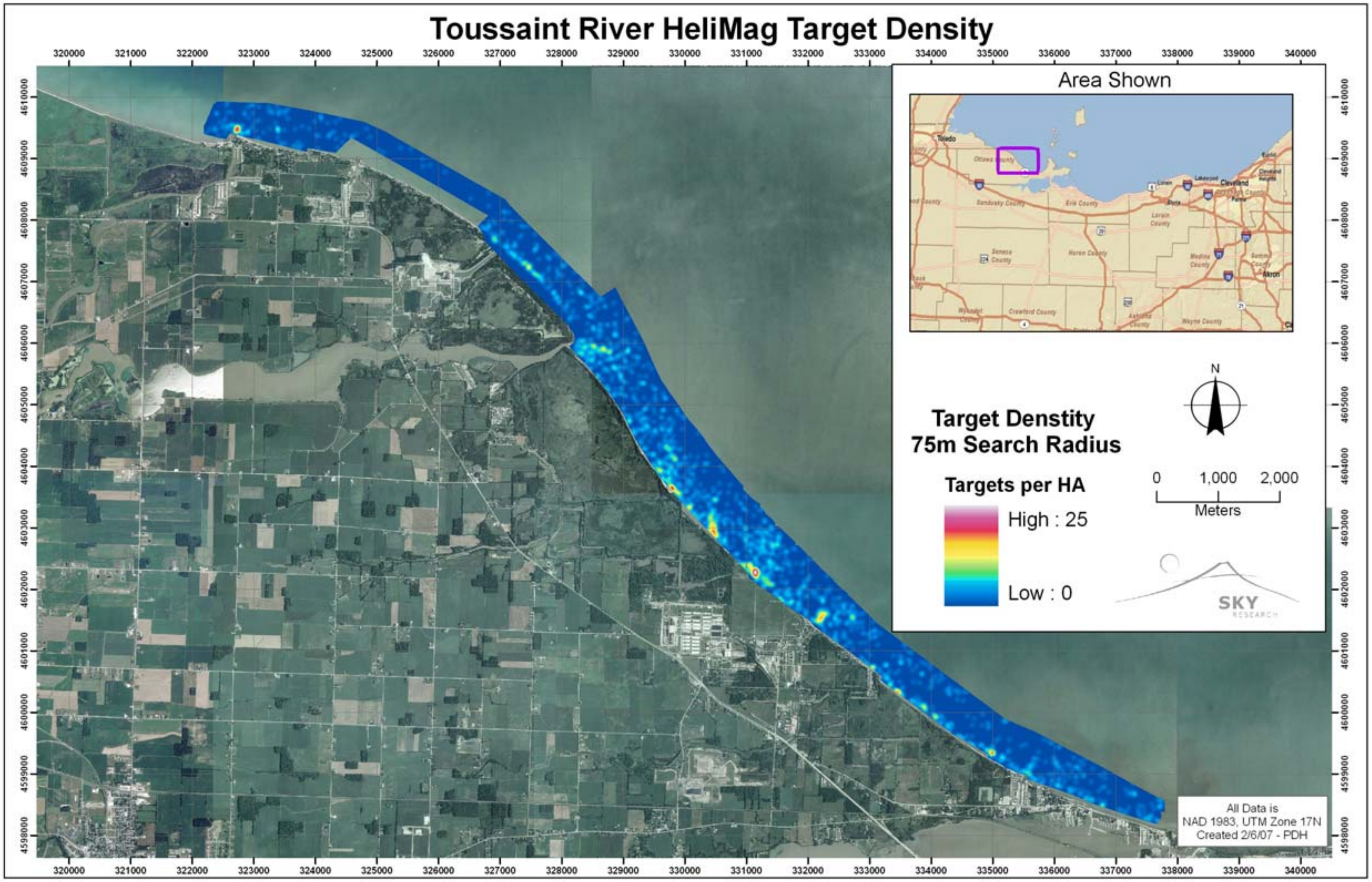


Figure 13. HeliMag Anomaly Density within the Survey Area at Toussaint River Site.

4.2 PERFORMANCE CRITERIA

Table 7 identifies the expected performance criteria for this evaluation, complete with post-demonstration performance results (quantitative) and/or definitions and descriptions (qualitative). Performance confirmation methods included the assessment of the use of HeliMag as a low-airborne survey technology; georeference accuracy; survey coverage; operating parameters; noise level, data density and spot spacing; and MEC parameter estimates.

Table 7. Confirmation Methods and Results for Helicopter Magnetometry

Type of Performance Objective	Primary Performance Criteria	Expected Performance	Observed Performance
Qualitative (Primary)	Ease of use and efficiency of operations	Efficiency and ease of use meets design specifications	Pass
Quantitative (Primary)	Geo-reference position accuracy for each sensor system	Horizontal: < 0.25 m Vertical: < 0.5 m	Horizontal: 0.6 m – 0.25 m; Vertical: 015 m – 0.39 m
Quantitative (Secondary)	Survey coverage	> 0.95 of planned survey area	> 0.95 of planned survey area
	Operating parameters (altitude, speed, overlap, production level)	Altitude: 1-3 m AGL; Speed: 15-20 m/s; Overlap: 10%; Production: 300 acres/day	Altitude: 1.5 – 2.5 m AGL (mean) Speed: Mean 17 m/s (land); 8-13 m/s (over water) Overlap: 10% (land); 37% (water) Production: averages from 239 – 484 acres/day
	Noise level (combined sensor/platform sources, post-filtering)	< 1 nT	< 0.2 nT
	Data density/point spacing	0.5 m along-track 1.5 m cross-track	< 0.2 m along-track 1.5 m cross tack (max)
	MEC parameter estimates	Size < 0.02 m; Solid Angle < 10º	Size: <0.02 m; Solid Angle < 8º

4.3 TECHNOLOGY COMPARISON

HeliMag provides efficient low-altitude DGM capabilities for metal detection at a resolution approaching that of typical ground survey methods. However, as compared to ground-based DGM methods, low-altitude surveys can be more limited by terrain, vegetation, and structural inhibitions to safe low-altitude flight.

5.0 COST ASSESSMENT

5.1 COST REPORTING

Cost information associated with the demonstration of all airborne technology, as well as associated activities, were tracked and documented before, during, and after the demonstration to provide a basis for determination of the operational costs associated with this technology. For this demonstration, Table 8 contains the cost elements that were tracked and documented for the Victorville demonstration for use as an example of demonstration costs. The individual demonstration costs are provided in the demonstration reports.

Costs include both operational and capital costs associated with the demonstration design and planning; salary and travel costs for support staff; equipment costs associated with aircraft, sensor and camera, support personnel, and costs associated with the processing, analysis, and interpretation of the results generated by this demonstration. Costs associated with site visit to collect post-survey data were not considered in the cost analysis, as the validation was conducted as part of the WAA pilot program.

Table 8. Cost Tracking[1]

Cost Category	Sub Category	Details	Costs ($)
Start-Up Costs	Pre-Deployment and Planning	Includes planning, contracting, site visit, and site inspection	$26,390
	Mobilization	Personnel mobilization, equipment mobilization, and transportation	$79,700
Operating Costs	Helicopter Survey	Data acquisition and associated tasks, including helicopter operation time	$326,446
Demobilization	Demobilization	Demobilization, packing, calibration line removal	$5,855
Data Processing and Analysis	Data Processing	Initial and secondary processing of data	$30,503
	Data Analysis	Analysis of airborne magnetometry datasets	$23,151
Management	Management and Reporting	Project related management, reporting and contracting	$39,318
TOTAL COSTS			
		Total Technology Cost	$531,363
		Acres Characterized	4,567
		Unit Cost	$116/acre

5.2 COST ANALYSIS

The cost of an airborne survey depends on many factors, including:

- Aircraft costs can vary depending on the provider of the aircraft.

[1] All costs reported for the demonstration include overhead and organization burden and fees.

- Length and number of flight lines required to survey the area.
- Climate and weather conditions, which can affect productivity
- Location of the site, which can influence the cost of logistics
- Amount of analysis required to sufficiently review the data

Aircraft costs are a major cost factor for any airborne survey. Significant variables and factors associated with the mobilization, data acquisition, and demobilization costs include the cost of aircraft time and stand by time. The cost of aircraft can vary depending upon the type of aircraft and operating costs. Stand-by time can also influence the cost of a survey and is typically assessed at the cost of one day of data collection (minimum of four hours were used for these demonstrations), including aircraft costs, labor and travel. For multi-day surveys, weather can be more of a variable and stand by time can increase costs. For the Former Camp Beale demonstration, the impact of hot weather limited the number of hours per day that low-altitude surveys could be safely conducted.

Mobilization and demobilization costs are most significantly a function of the distance from the home base for the aircraft. In addition to the cost of mobilizing and demobilizing the aircraft, the cost of mobilizing equipment (sensors and GPS equipment) can add significantly to costs. For longer mobilization distances, the costs of equipment rental for mobilization and demobilization can be substantial. Therefore, for a site requiring a longer mobilization distance, the mobilization and demobilization can take up a correspondingly larger amount of the budget, especially for a relatively small site.

Data processing and analysis costs are generally linear with project size and site complexity; other influential factors include the objectives of the program and associated data requirements. Processing costs and data deliverable times have been decreasing with experience at multiple sites, automation of processing and analysis routines and increased computing power resulting in faster processing.

Project management and reporting were a somewhat significant cost for this demonstration, as the project was conducted under the WAA pilot program and required more meetings and reporting than would generally be expected for a production level survey.

5.3 TYPICAL AIRBORNE SURVEY COSTS

Mobilization distance, site size, site conditions, and project objectives can influence the costs of data collection and analysis.

To generalize typical airborne survey costs, several scenarios are presented in Table 9 for several sizes of survey sites. For these scenarios, the following assumptions have been made: the site is generally amenable with respect to topography, vegetation and other potential obstructions to low-altitude surveys; data analysis is for the detection of target areas and inversions will either be performed for a small select of anomalies or none at all; and the mobilization distance for the helicopters corresponds to four hours’ flight.

Each scenario includes several categories of costs associated with a variety of tasks, including the following:

- Planning, Preparation and Management
  - Review of available historical information
  - LiDAR and orthophotography data review (if data available)
  - Work plan development
  - Logistics planning
  - Ground control planning
  - Flight planning
  - Staff preparation and equipment review
  - Management including contracting, client interaction, etc.
- Mobilization/demobilization.
  - 4 hours of flight time each direction
  - Labor for pilot, co-pilot, sensor operator, ground survey team
  - Cost of mobilizing equipment (sensors, boom, DAS, fuel truck, trailer, GPS equipment, etc.)
  - Travel costs
- Data Acquisition
  - Helicopter usage costs (minimum of four hours of flight time per day)
  - Equipment costs
  - Labor for pilot, sensor operator, ground survey team, data processor
  - Travel costs
- Data Processing, Analysis and GIS Products
  - Additional data processing
  - Data analysis
  - Quality control
  - GIS products, including maps
- Reporting/Documentation
  - Final report
  - Metadata development
  - Data compilation and delivery
  - Data archiving

Table 9. Estimated Costs Scenarios for Helicopter Magnetometry

Cost Category	1,000 Acre Site	5,000 Acre Site	7,500 Acre Site	10,000 Acre Site
Planning, Preparation and Management	$32,000	$47,000	$55,000	$62,000
Mobilization/Demobilization	$40,000	$40,000	$40,000	$40,000
Data Acquisition Surveys	$82,000	$410,000	$612,000	$817,000
Data Processing, Analysis and GIS Products	$12,000	$40,000	$54,000	$67,000
Reporting and Documentation	$12,000	$15,000	$20,000	$30,000
Total Costs	**$178,000**	**$552,000**	**$781,000**	**$1,016,000**
Costs per Acre	**$178**	**$110**	**$104**	**$102**

As discussed, additional costs would be assumed for a greater mobilization distance. For example, a mobilization requiring 8 hours of flight time would increase the mobilization/demobilization costs by an estimate of over 75% over the costs provided in Table 9; a mobilization distance of 16 hours of flight time, would increase the mobilization/demobilization costs by an estimate of nearly three times over the costs provided in Table 9. The data acquisition survey cost estimates assume on average 300-400 acres of surveys per day. The actual costs of a project can increase or decrease depending on production rates achieved. One issue to note is that weather can often decrease the production survey rate, increasing the overall number of days required to complete surveys. In addition, standby day rates are often added as an additional cost to a project and are typically the cost of the minimum number of aircraft usage per day plus travel costs.

The data processing and analysis cost estimates assume that for a WAA project, anomaly selection and QC will not require extensive filtering. Therefore, sites requiring more analysis – such as sites with significant geology - will require additional labor for data analysis. In addition, the costs for completing dipole-fit modeling above the calibration flight results analysis is not included in the estimates above.

The estimates in Table 9 above assume that an on-line mapping site would be created for client interaction. The costs for the GIS products would be somewhat lower without on-line mapping. Last, the reporting for helicopter magnetometry projects has become somewhat standardized; the reporting costs could increase if a significantly different format is required.

5.4 COST CONCLUSIONS

A number of factors should be considered for DoD-wide application of WAA, including data acquisition, when evaluating the appropriateness of helicopter technology and potential for cost savings. Sites must be large enough to justify the deployment of aircraft and equipment to conduct a survey. Climatic conditions and terrain can limit the results of surveys. In amenable sites, the use of helicopter magnetometry can focus the use of ground survey technology and can provide substantial cost savings through footprint reduction.

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

HeliMag technology provides a lower cost per acre surveyed for site characterization than ground-based DGM methodologies. However, the cost of deployment of the technology generally precludes the use on very small sites or sites requiring relatively low total acreage of coverage because of the expense of mobilizing a helicopter and equipment. Ground based methods that use transects to cover 1 to 2% of a site will prove to be more cost effective than the Helimag technology, unless the site is large enough to justify the initial Helimag mobilization costs. However, for sites with challenging ground access issues, HeliMag will be a cost effective WAA technology that provides site characterization information to assist in the determination of MRS boundaries.

6.2 PERFORMANCE OBSERVATIONS

On amenable sites, deployment of HeliMag technology and analysis of the results is a well understood and straight forward process. The data collection, processing and analysis techniques are well documented and have been demonstrated on a number of sites. The technology can survey hundreds of acres per day, and data analysis can be completed in a relatively short period of time. For sites with more complicated site characteristics, such as vegetation, topography, geology, etc. the use of the technology should be evaluated prior to mobilization in consideration of project objectives.

6.3 SCALE-UP

There are no scale-up issues with this technology; HeliMag can be utilized as demonstrated to characterize a large number of sites. LiDAR and orthophotography data (typically collected as the first step in a WAA investigation) should be analyzed to determine areas where HeliMag can be deployed to characterize areas of the site requiring further investigation. In addition, the size of the areas requiring further investigation should be considered; completing helicopter surveys on very small sites may be prohibitively expensive in consideration of the cost to mobilize the helicopter and equipment. Conversely, very large sites may be very expensive to complete a 100% site survey; transects can be utilized for these very large sites for a more cost effective characterization.

6.4 OTHER SIGNIFICANT OBSERVATIONS

Low altitude helicopter surveys can efficiently and effectively characterize a number of sites. As with the use of any technology, the site characteristics should be carefully considered for a prospective WAA site in order to understand the likelihood of detection for various types of munitions using HeliMag technology.

6.5 LESSONS LEARNED

The primary benefit of this technology is in rapid characterization of large open areas, commonly referred to as footprint reduction. LiDAR and orthophotography data, if collected, should be

analyzed prior to deployment of helicopter technology for topography and vegetation impediments to low altitude flight. In addition, expected geologic conditions should be evaluated. Last, it should be understood that as a WAA technology, the goal of utilizing helicopter magnetometry technology is to identify areas of elevated concentrations of MEC and not individual target detection. As a WAA technology, the most cost effective use of this technology is for the characterization of larger sites (i.e. sites thousands of acres in size).

6.6 END-USER ISSUES

Implementing WAA for production level surveys should include end-users in the project. For this project, ESTCP created WAA Advisory Group to understand and evaluate potential end-user issues and concerns that can impact the widespread implementation of WAA technologies.

End-users can be provided on-line access to WAA data and analytical tools through the use of geographic information systems (GIS). A WAA GIS demonstration (MM-0537) was conducted throughout the time period of the WAA demonstrations.

6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

The ESTCP Program Office established a WAA pilot program Advisory Group to facilitate interactions with the regulatory community and potential end-users of this technology. Members of the Advisory Group included representatives of the USEPA, State regulators, USACE officials, and representatives from the services. ESTCP staff worked with the Advisory Group to define goals for the pilot program and develop Project Quality Objectives.

There will be a number of issues to be overcome to allow implementation of WAA beyond the pilot program. Most central is the change in mindset that will be required if the goals of WAA extend from delineating target areas to collecting data that are useful in making decisions about areas where there is not indication of munitions use. Therefore, the challenge for adoption of a WAA approach with respect to regulatory acceptance may be the collection of sufficient data and evaluation that the applicability of these technologies to uncontaminated land and understanding of the results. Similarly, demonstrating that WAA data can be used to provide information on target areas regarding boundaries, density and types of munitions to be used for prioritization, cost estimation and planning will require that the error and uncertainties in these parameters are well understood.

7.0 REFERENCES

Nelson, H., J. McDonald and D. Wright, 2005. "Airborne UXO Surveys Using the MTADS," Naval Research Laboratory NRL/MR/6110--05-8874.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. 2003. Report of the Defense Science Board Task Force on Unexploded Ordnance. 20301-3140. December 2003.

Sky Research. 2008. Demonstration of Helicopter Multi- Sensor Towed Array Detection System, Former Camp Beale. [Placeholder].

Sky Research. 2008. Demonstration of Helicopter Multi- Sensor Towed Array Detection System at Pueblo Precision Bombing Range #2, Colorado. Draft Final Report. February 2008.

Sky Research. 2008. Demonstration of Airborne Wide Area Assessment Technologies at Kirtland Bombing Range, New Mexico. Draft Final Report. January 2008.

Sky Research. 2007. Demonstration of Airborne Wide Area Assessment Technologies at Toussaint River, Ohio Final Report. Final Report. June 2007.

Tuley, M. and E. Dieguez, "Analysis of Airborne Magnetometer Data from Tests at Isleta Pueblo, New Mexico", IDA Document D-3035, July 2005.

Versar. 2005. Conceptual Site Models to Support ESTCP Wide Area Assessment.

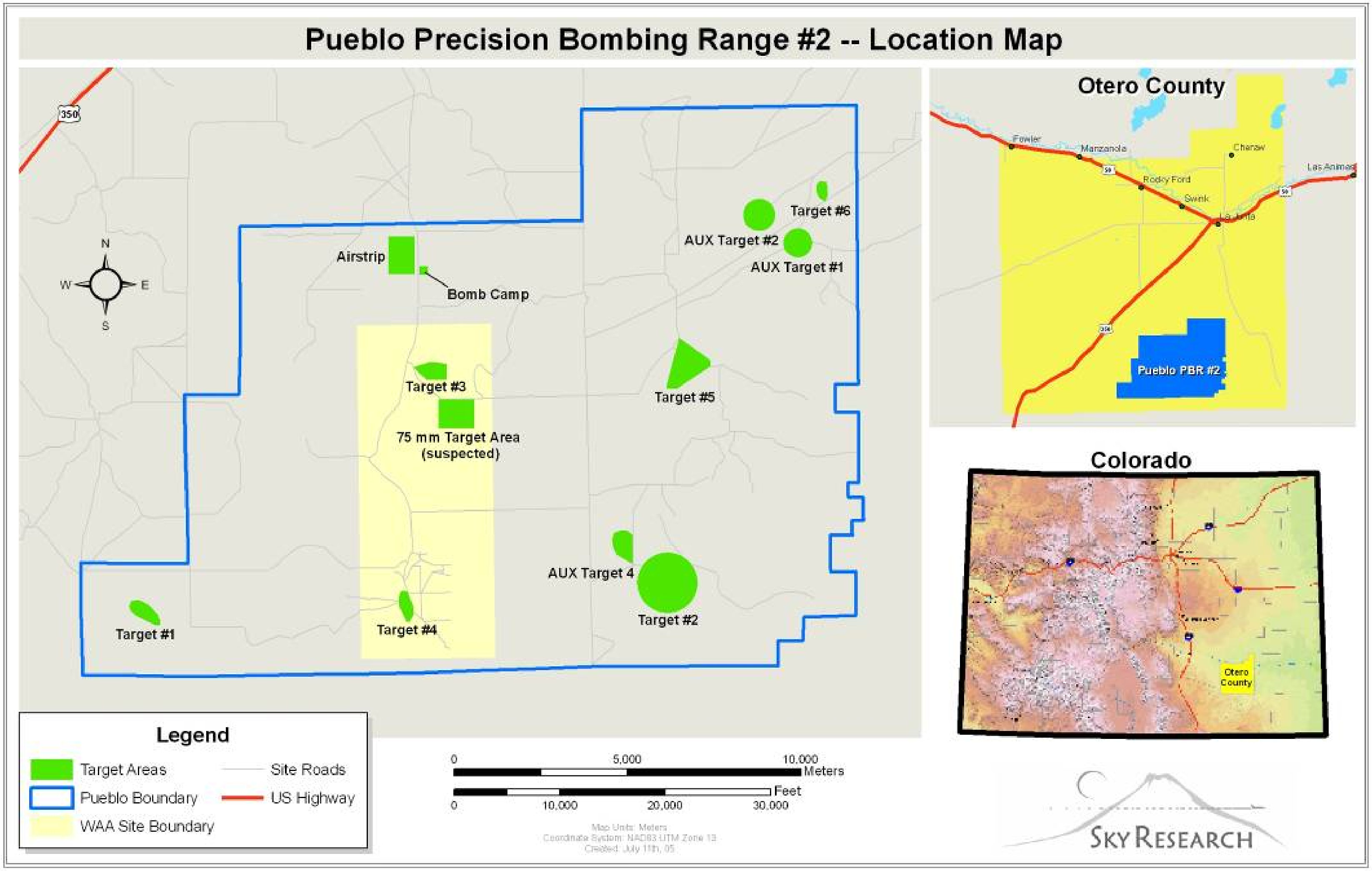
This page left blank intentionally.

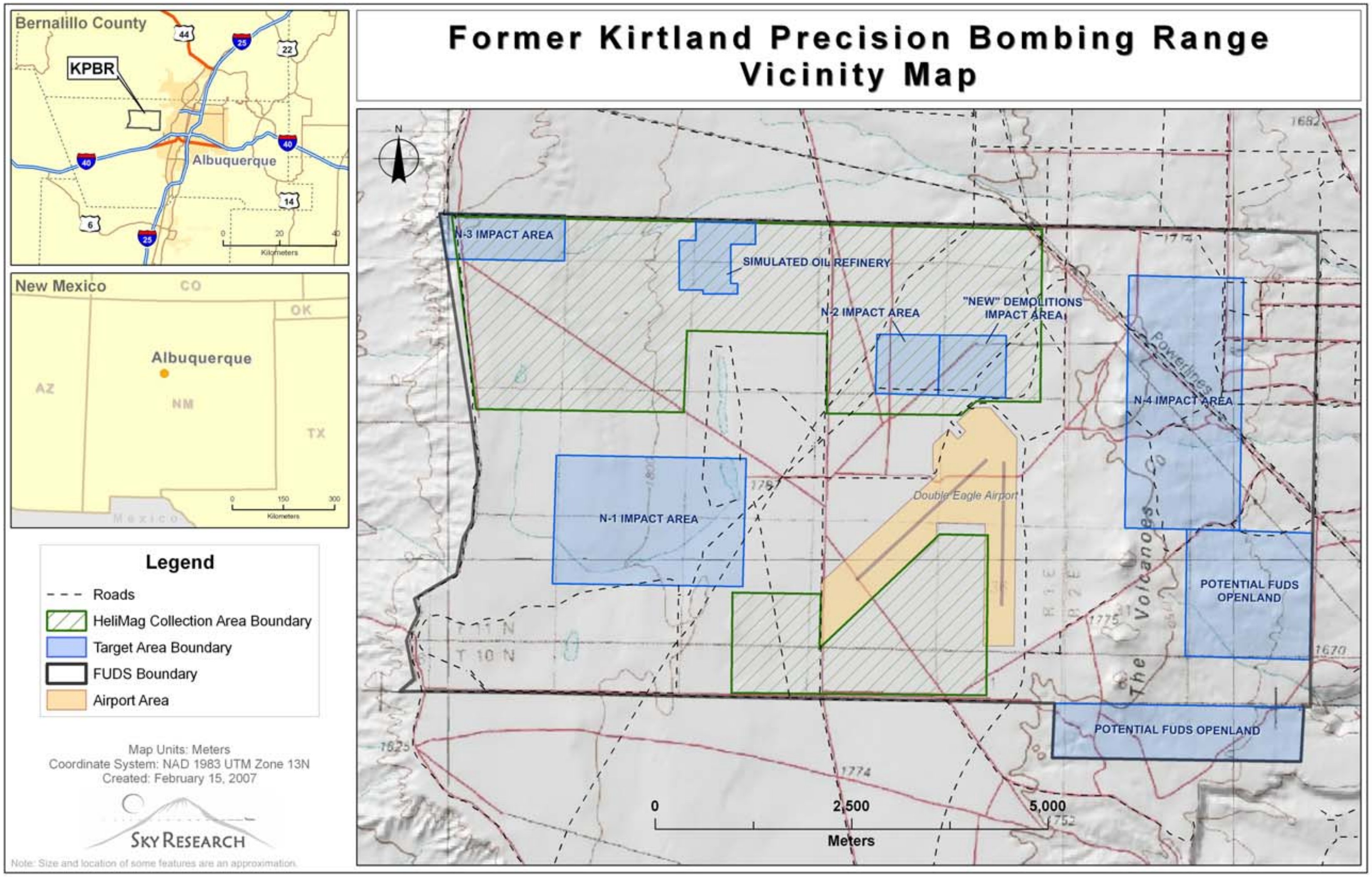
APPENDIX A

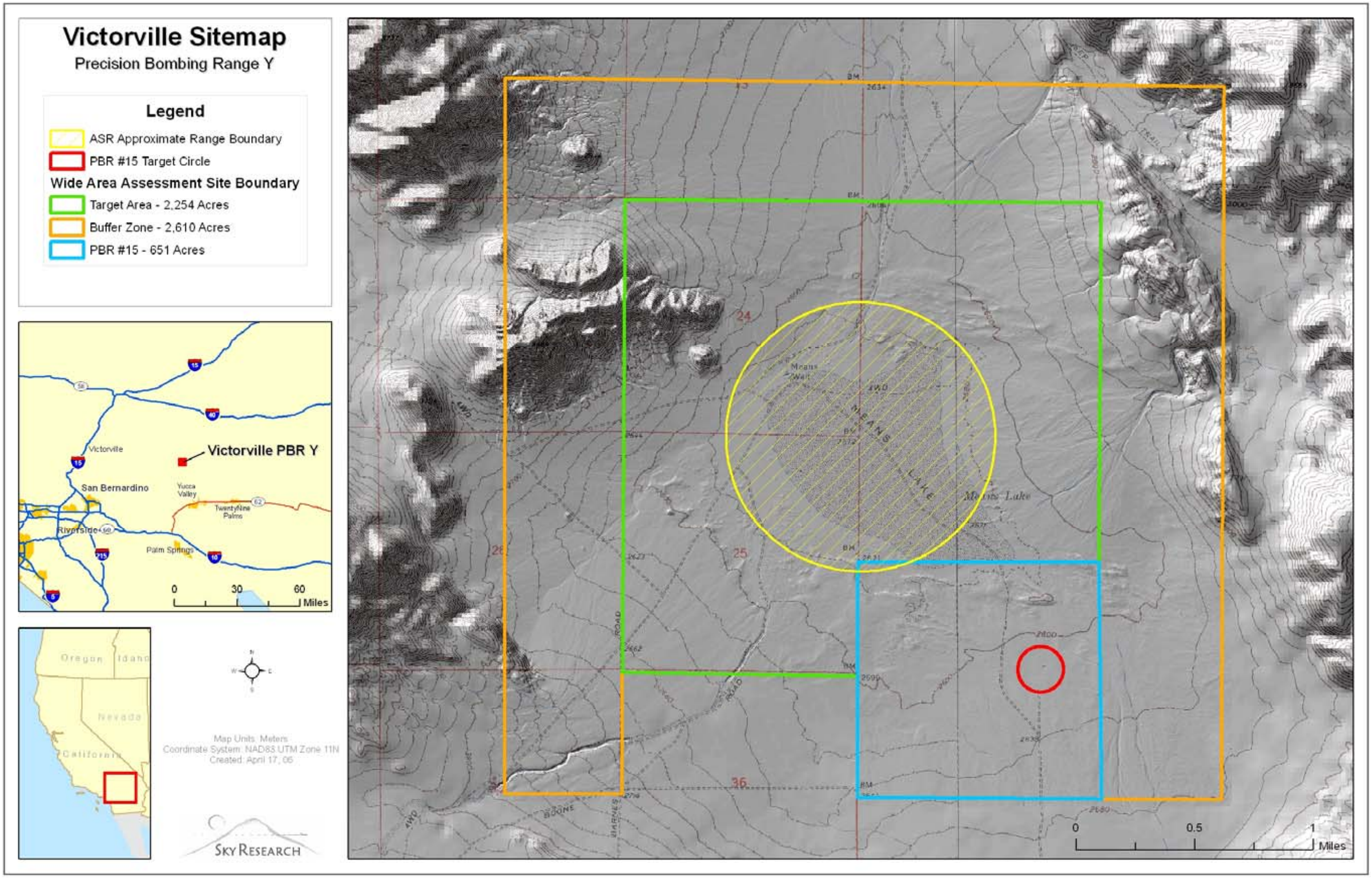
POINTS OF CONTACT

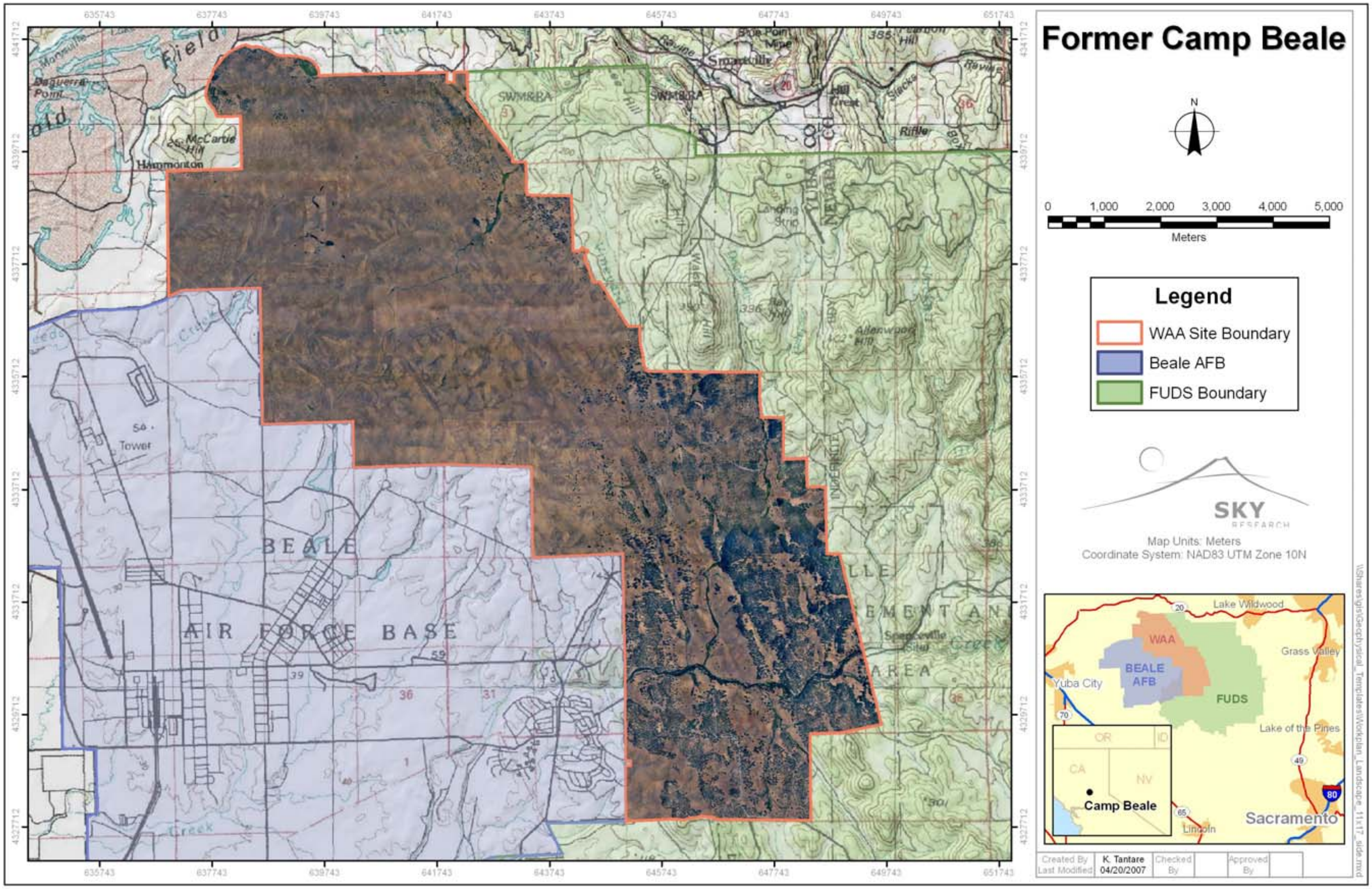
Point of Contact	Organization	Phone Fax E-mail	Role
Dr. John Foley	Sky Research, Inc. 445 Dead Indian Road Ashland, OR 97520	(Tel) 541.552.5141 (Fax) 720.293.9666	Principal Investigator
Mr. Dave Wright	Sky Research, Inc. 445 Dead Indian Road Ashland, OR 97520	(Tel) 541.552.5141 (Fax)	Co-Principal Investigator
Ms. Terri Ayers	Sky Research, Inc. 445 Dead Indian Road Ashland, OR 97520	(Tel) 541.552.5113 (Fax) 541.488.4606	Project Manager
Mr. Jerry Hodgson	USACE Omaha District 215 N. 17th Street Omaha, NE 68102-4978	(Tel) 402.221.7709 (Fax) 402.221.7838	Federal Advocate
Mr. Hollis (Jay) Bennett	US Army R&D Center (CEERD-EE-C) 3909 Halls Ferry Road Vicksburg, MS 39180-6199	(Tel) 601.634.3924	DoD Service Liaison

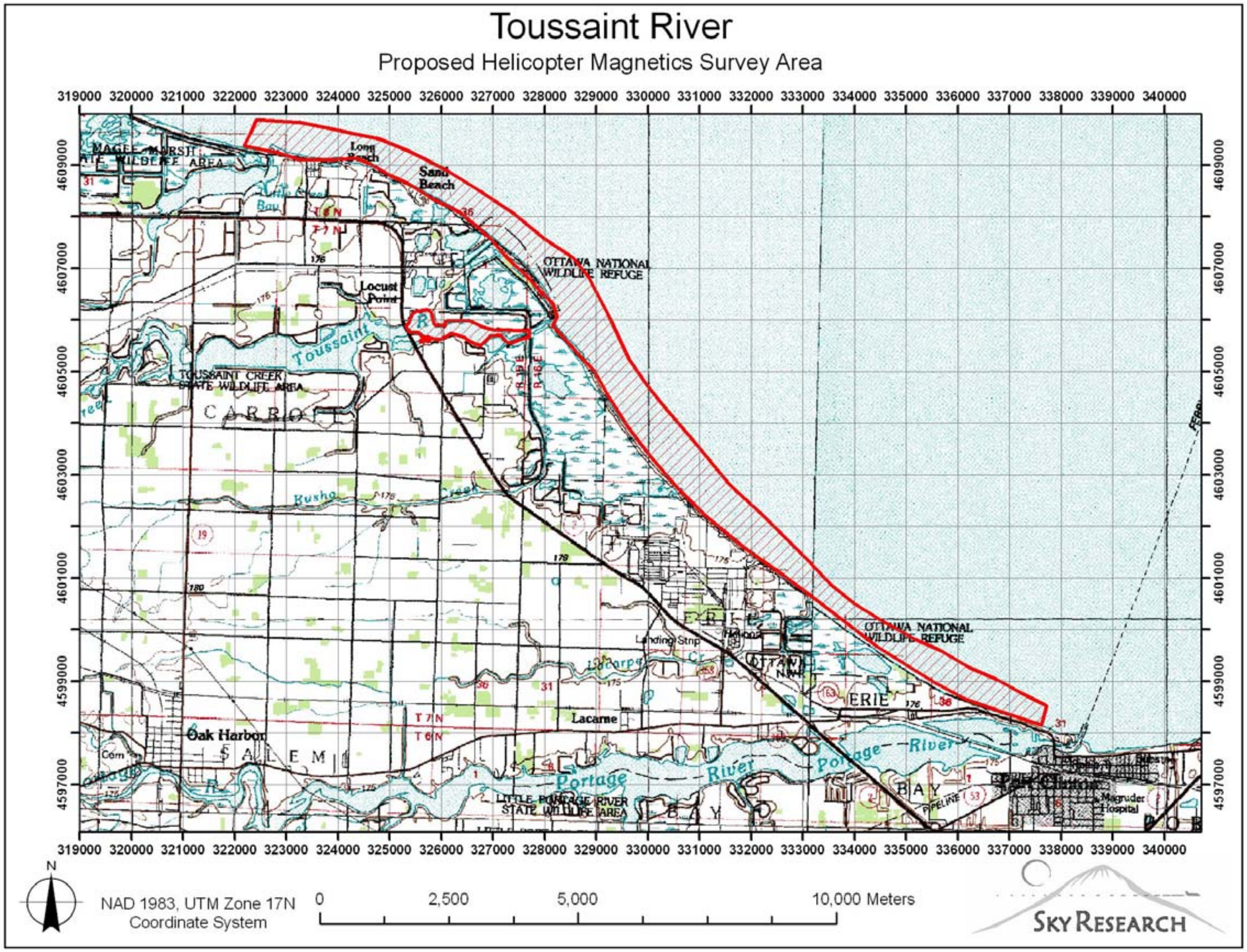
Appendix B: Demonstration Site Maps


Pueblo Precision Bombing Range #2 -- Location Map
Otero County
Colorado
Airstrip
Bomb Camp
Target #1
Target #2
Target #3
Target #4
Target #5
Target #6
AUX Target #1
AUX Target #2
AUX Target 4
75 mm Target Area (suspected)
Pueblo PBR #2
Legend
Target Areas
Site Roads
Pueblo Boundary
US Highway
WAA Site Boundary
Meters
Feet
Sky Research

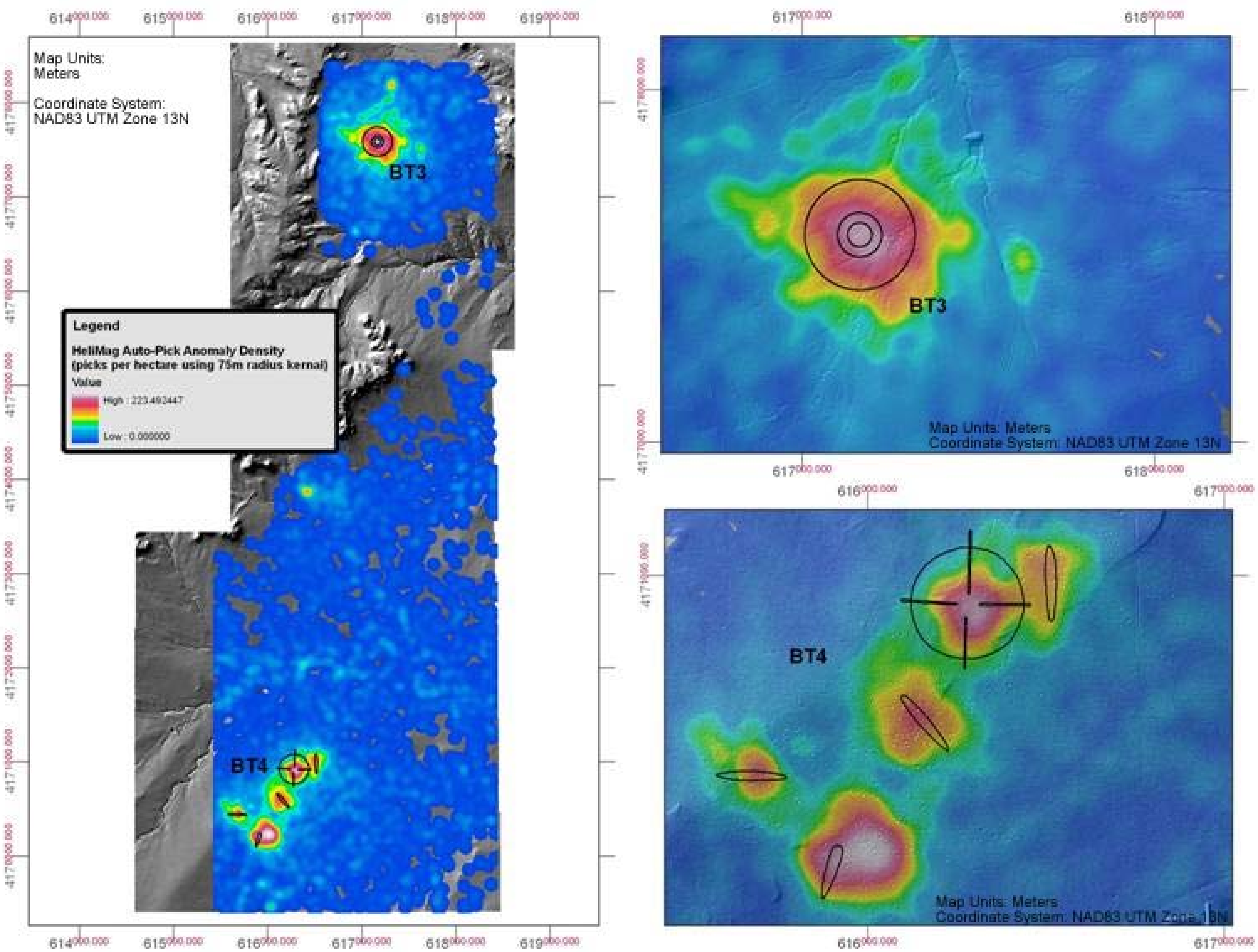

Former Kirtland Precision Bombing Range
Vicinity Map
Bernalillo County
KPBR
Albuquerque
New Mexico
CO
OK
AZ
NM
TX
Legend
Roads
HeliMag Collection Area Boundary
Target Area Boundary
FUDS Boundary
Airport Area
Map Units: Meters
Coordinate System: NAD 1983 UTM Zone 13N
Created: February 15, 2007
SKY RESEARCH
N-3 IMPACT AREA
SIMULATED OIL REFINERY
N-2 IMPACT AREA
"NEW" DEMOLITIONS IMPACT AREA
N-4 IMPACT AREA
Powerlines
N-1 IMPACT AREA
Double Eagle Airport
POTENTIAL FUDS OPENLAND
POTENTIAL FUDS OPENLAND
The Volcanoes
T 11 N
T 10 N
0
2,500
5,000
Meters


Victorville Sitemap
Precision Bombing Range Y
Legend
ASR Approximate Range Boundary
PBR #15 Target Circle
Wide Area Assessment Site Boundary
Target Area - 2,254 Acres
Buffer Zone - 2,610 Acres
PBR #15 - 651 Acres
Victorville PBR Y
Victorville
San Bernardino
Riverside
Palm Springs
0 30 60 Miles
Map Units: Meters
Coordinate System: NAD83 UTM Zone 11N
Created: April 17, 06
SKY RESEARCH
Means Lake
0 0.5 1 Miles

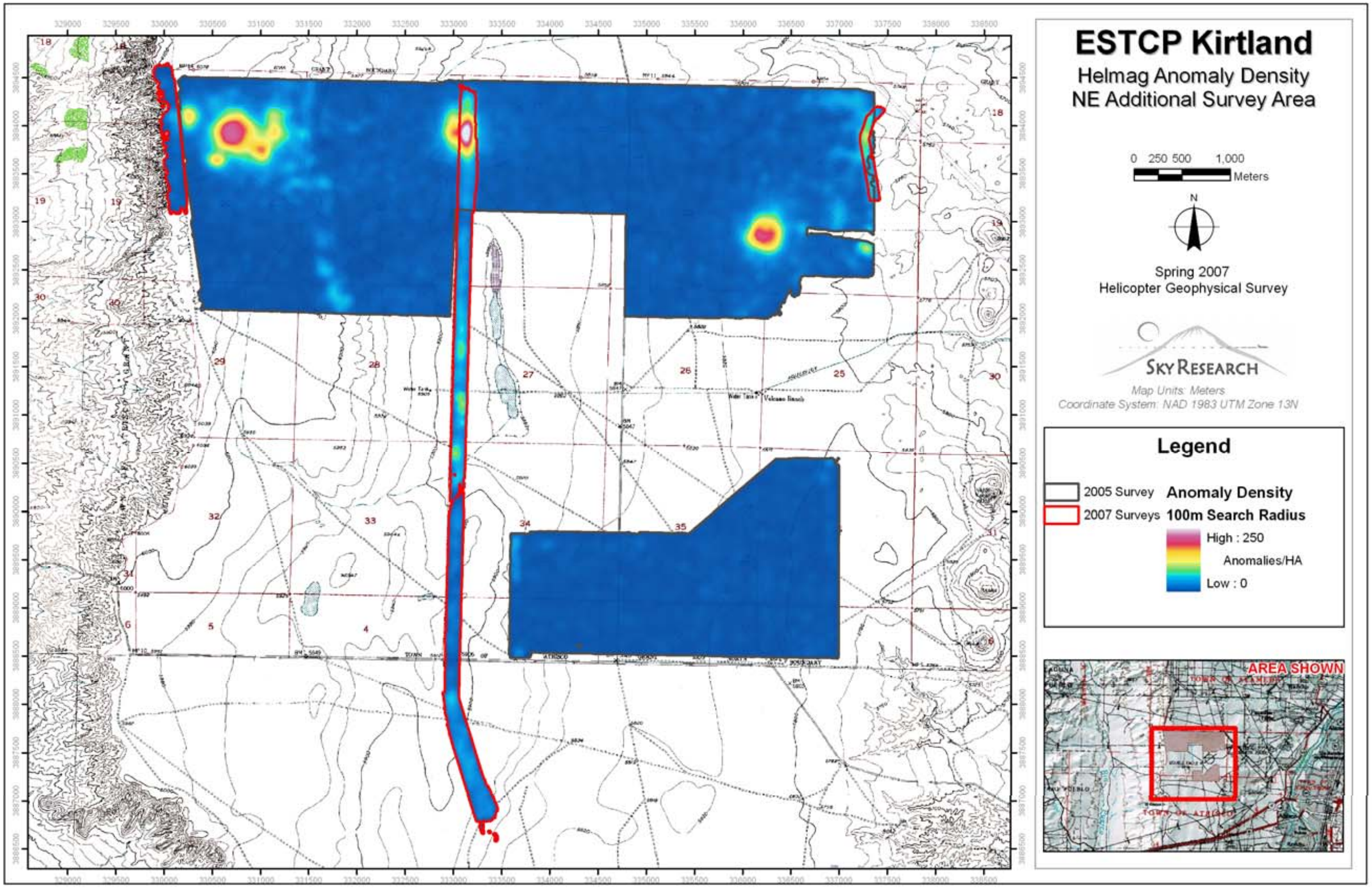

Former Camp Beale
N
0 1,000 2,000 3,000 4,000 5,000
Meters
Legend
WAA Site Boundary
Beale AFB
FUDS Boundary
SKY RESEARCH
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
BEALE AIR FORCE BASE
Lake Wildwood
Grass Valley
WAA
BEALE AFB
FUDS
Yuba City
Lake of the Pines
Camp Beale
Sacramento
Lincoln
Created By Last Modified K. Tantare 04/20/2007
Checked By
Approved By


Toussaint River
Proposed Helicopter Magnetics Survey Area
Long Beach
Sand Beach
OTTAWA NATIONAL WILDLIFE REFUGE
Locust Point
Toussaint
TOUSSAINT CREEK STATE WILDLIFE AREA
CARROLL
Landing Strip
ERIE
Lacarne
Oak Harbor
SALEM
Portage River
LITTLE PORTAGE RIVER STATE WILDLIFE AREA
BAY
Port Clinton
Magruder Hospital
NAD 1983, UTM Zone 17N
Coordinate System
0
2,500
5,000
10,000 Meters
SKY RESEARCH

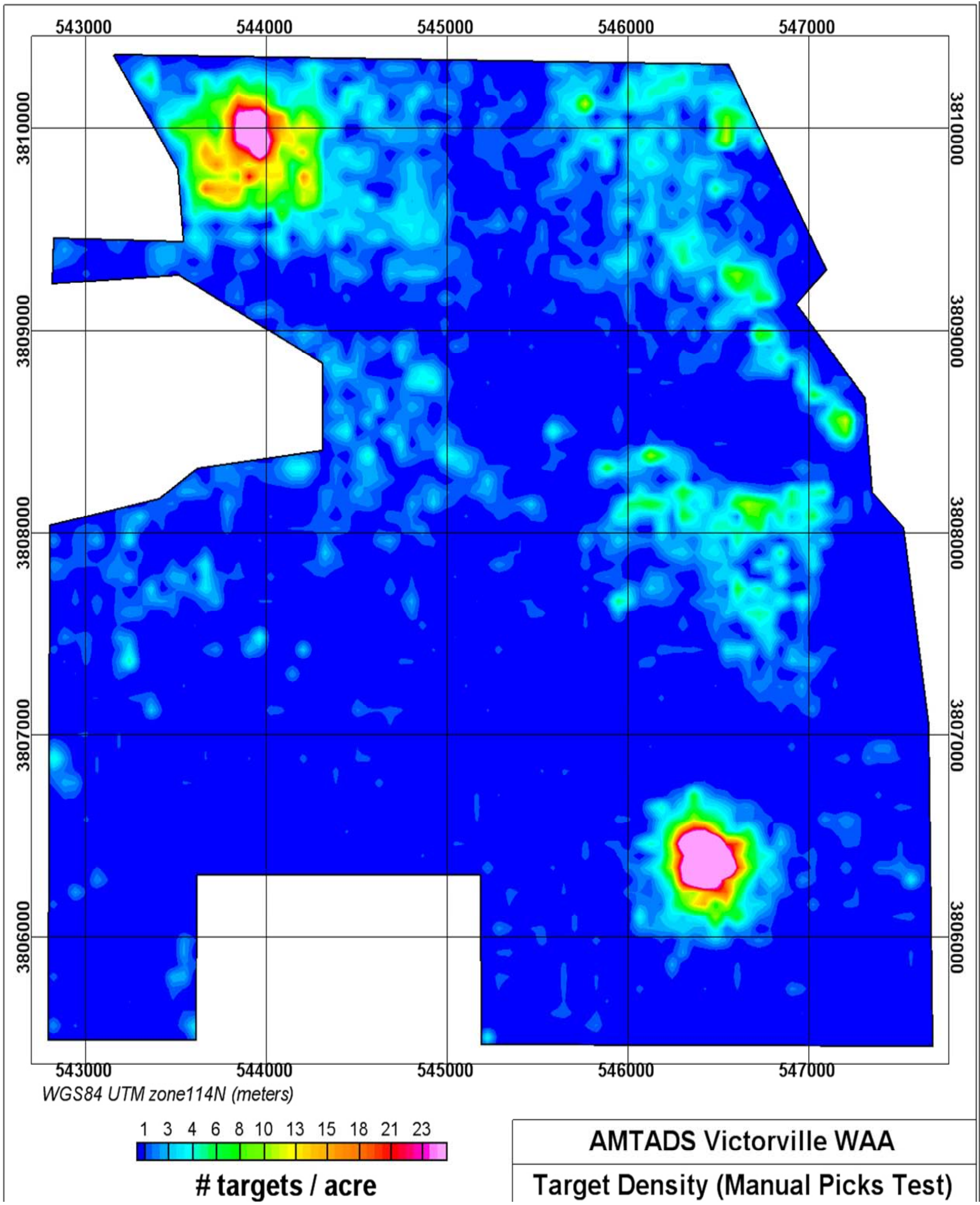
Appendix C: Anomaly Density Maps



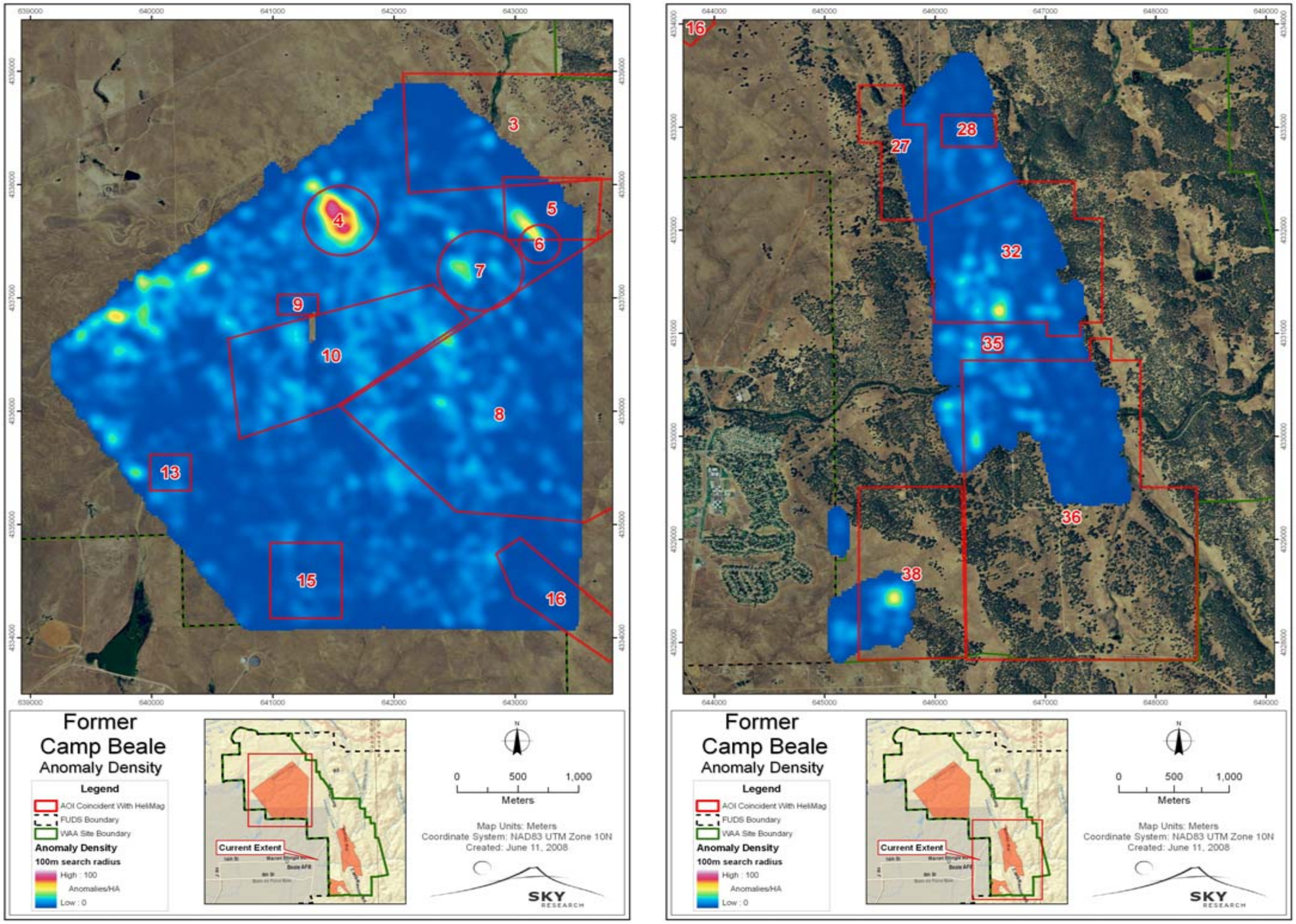
Anomaly Density at Pueblo PBR #2



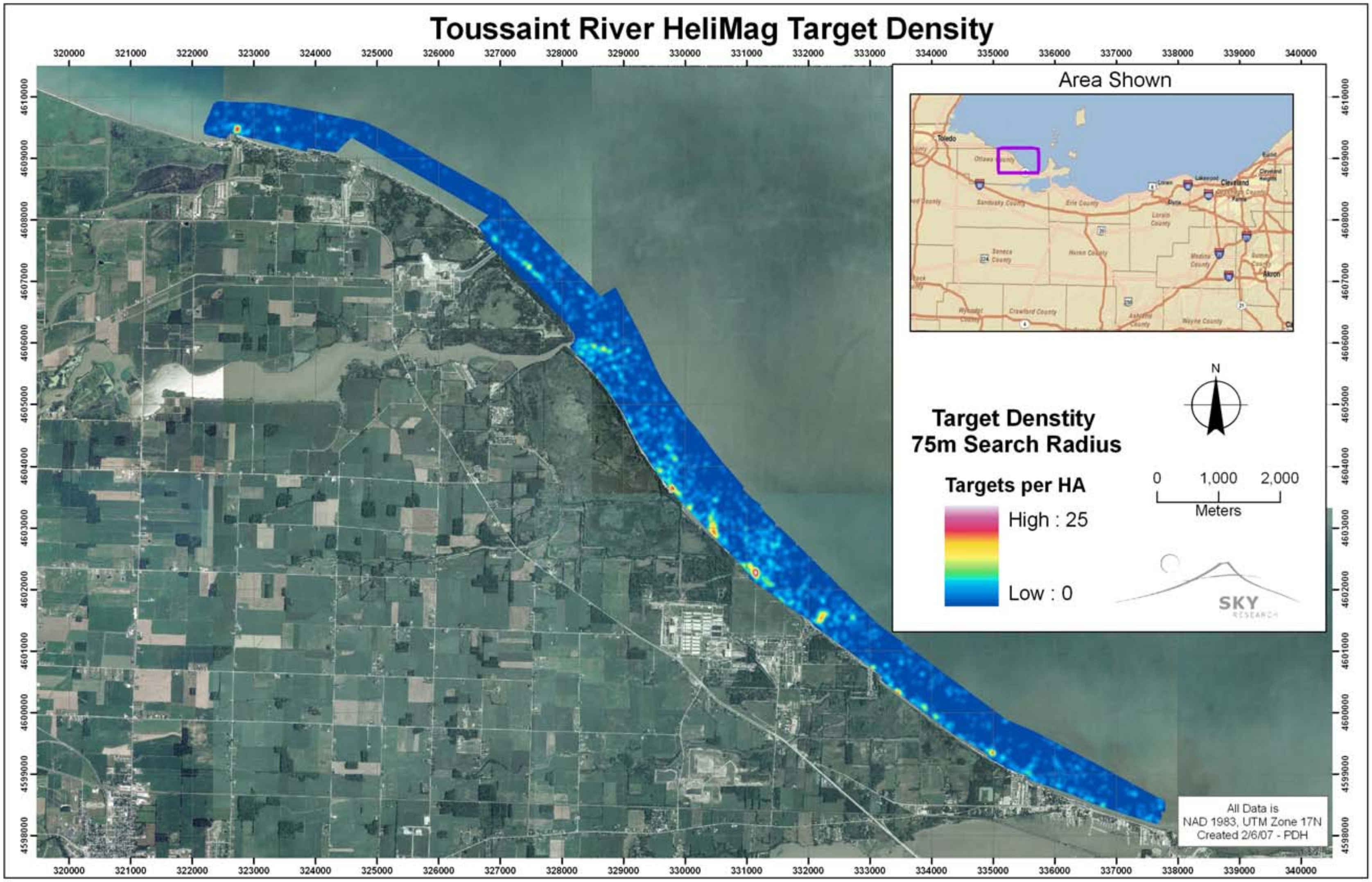
Anomaly Density at Kirtland PBR



Anomaly Density at Victorville PBR



Anomaly Density at Former Camp Beale



Anomaly Density at Toussaint River

ESTCP Program Office

901 North Stuart Street
Suite 303
Arlington, Virginia 22203

(703) 696-2117 (Phone)
(703) 696-2114 (Fax)

e-mail: estcp@estcp.org
www.estcp.org